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THE INSTITUTION OF ELECTRICAL ENGINEERS

JOURNAL

VOLUME 4 NO. 39 MARCH 1958

VOLUME 4 NUMBER THIRTY-NINE MARCH 1958 ©

JOURNAL

OF THE INSTITUTION OF ELECTRICAL ENGINEERS

SAVOY PLACE LONDON W.C.2 *Telephone* TEMPLE BAR 7676 *Telegrams* VOLTAMPERE PHONE LONDON

PUBLISHED MONTHLY PRICE SEVEN SHILLINGS ANNUAL SUBSCRIPTION TWO POUNDS

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Advertising Office TERMINAL HOUSE, GROSVENOR GARDENS, LONDON, S.W.1. *Telephone* SLOANE 7266. *Telegrams* INDULICITY, SOWEST, LONDON

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VOLUME 4 NUMBER 39 MARCH 1958

A NEW POWER HORIZON

IN THIS ISSUE APPEARS A REVIEW ARTICLE BY Dr. T. E. Allibone on the peaceful uses of nuclear energy. Most of the article is devoted to nuclear fission and its applications, for until two months ago the story of progress in the coupling of nuclear energy to peaceful enterprise had been a story of the exploitation of fission. And how swiftly the story has moved. It is only sixteen years since the first fission reactor began working in Chicago, only twelve since the Atomic Energy Research Establishment was founded at Harwell, only two since Calder Hall was commissioned. Now the use of radioisotopes in industry, agriculture and medicine is growing rapidly, and some half-dozen nuclear power stations of the graphite-moderated gas-cooled type are springing up in the British Isles. As Dr. Allibone writes, 'It is indeed astonishing that, within fifteen years of the first reactor being constructed, reactors can be built to deliver electricity at a price competitive with the coal-fired station'.

But an up-to-date account of the peaceful uses of nuclear energy must naturally touch on fusion reactions—on the possibility of thermo-nuclear fusion for power production. Whether we have reached for fusion reactions a stage similar to that reached in 1942 for fission reactions seems debatable. At present the energy produced in Zeta is only about 10^{-12} of that provided for its toroidal discharge by the external capacitors. But one can be forgiven for feeling that Britain's atomic physicists have trodden the most difficult part of the road towards the first thermo-nuclear power station, and that, although a temperature of 5×10^6 °C may be low on the thermo-nuclear scale, its attainment represents a significant, and perhaps a critical, achievement. Many problems of physics, and later of engineering, will have to be solved before the world can use deuterium from sea water as a fuel, but this magnificent result of man's scientific and technical endeavour now seems likely to be realized this century—whether Sir John Cockcroft's rough estimate of twenty years ahead proves too sanguine or too cautious.

Doubtless the first fully engineered fusion reactor for power production will look vastly different from Zeta. But it will probably still be recognizable by the electrical engineer as a giant pulse transformer: it will in fact be primarily a piece of electrical equipment, however one classifies the nuclear reactions taking place inside it. It is perhaps significant that Zeta involves heavy currents produced by a light-current technique—a marriage of two sides of electrical engineering for what will almost certainly be the ultimate source of the world's energy. Moreover, if it becomes possible to tap a fusion reactor's energy output in electrical form back through its own transformer, instead of in thermal form through a cooling fluid, electrical energy will for the first time be generated by truly electrical equipment. Then boilers, turbines, condensers and cooling towers will gradually disappear from our power stations.

Whether or not the direct conversion from nuclear to electrical energy proves practicable in the twentieth century, the station engineer of the thermo-nuclear age will need to be more of a physicist than he is at present. No doubt, as in the first fission-reactor stations, he will have a team of scientific and engineering specialists to assist him—and a Government report arising from the Windscale accident has in fact stressed the necessity of having such specialists available at nuclear works. But, with fusion reactors, operation and maintenance are likely to be more of an electrical engineer's commitment than they are with fission reactors. Thus the supply engineer concerned with generation rather than transmission and distribution would do well to cast his eyes with increasing frequency at the new horizon of physics that confronts him.

The Institution, through the British Nuclear Energy Conference, has in recent years been keeping its members scientifically informed about fission reactions. Nevertheless only three out of the eleven B.N.E.C. papers and lectures sponsored by The Institution have been within the compass of the Supply Section. It is true that much of the science and technology of present-day reactors is non-electrical, but there is surely now a good case for arranging, for the benefit of supply engineers particularly, more lectures of the type delivered by Dr. J. V. Dunworth in December last year.

THE CIRCLE OF KNOWLEDGE

The neglect of science by humanists and of the arts by engineers results in the cultural impoverishment of both. At the managerial level there is a lack of men with the wisdom and breadth of knowledge that spring from a comprehensive education—a lack that is felt keenly in industry and commerce, administration and Parliament. Britain's failure to maintain her industrial leadership of the world has thus been aggravated by her neglect of a sound educational policy.

This is the theme of Professor Cullwick's article, which is based on his Chairman's Address to the North Scotland Sub-Centre at Dundee and Aberdeen on the 14th and 15th November 1957.

PROFESSOR E. G. CULLWICK, O.B.E., M.A., D.SC., F.R.S.E., MEMBER

THE Institution of Electrical Engineers, as Appleyard so aptly says in his *History*, stands at the confluence of the streams of academic and practical knowledge. In all its work it strikes a balance between the theoretical and the practical, and between basic electrical science and applied. In this balance lies its strength, for the practice of electrical engineering has grown, and must continue to grow, by continuous nourishment from the fascinating and ever-expanding store of fundamental electrical science. The Romans built excellent roads and bridges without benefit of mathematical theories of soil mechanics and elasticity, Newcomen and Watt developed the steam engine before Joule established the mechanical equivalent of heat, but who has heard of an electric generator before Faraday, or of true radiocommunication before Maxwell and Hertz?

Among the pioneers of electromagnetic theory Clerk Maxwell is supreme, just as Faraday, enshrined in the seal of The Institution, is first among experimenters. Scotland should indeed be proud of Maxwell, more particularly since Britain as a whole did not contribute nearly so much to the early development of electrical theory as did France and Germany. The laws of electricity and magnetism can be formulated exactly only in the language of mathematics, and until Maxwell Britain had no names, except perhaps that of William Thomson, another Scot, to compare with those of Poisson, Ampère, Clausius, Weber, Neumann and Ludwig Lorenz. Had Maxwell not lived, no doubt electrical science and its practical applications would have developed none the less, but he, developing Faraday's line of thought, gave it a direction that has influenced the whole of modern physics.

Maxwell was born in Edinburgh in 1831, the year of Faraday's greatest discovery. At the age of ten he entered Edinburgh Academy in clothes specially designed by his father, which, alas, did not meet with the approval of his schoolfellows. After three years at Edinburgh University he went to Cambridge, first to Peterhouse and then to Trinity, and in 1854 obtained second place in the mathematical tripos, sharing with Routh, the senior wrangler, the honour of the Smith's Prize. His brilliance earned him a fellowship of Trinity, and it was during the next two years that he published his first paper on electromagnetism, on *Faraday's Lines of Force*, the beginning of the work which culminated in his greatest achievement.

In 1856, on the death of his father, he became laird of the small estate of Glenlair and Middlebie in Dumfries, just at the time he was appointed Professor of Natural Philosophy in Marischal College. In 1860, however, the two Aberdeen Colleges, Marischal and King's, were combined in one university and Maxwell's chair was abolished. Thus, at the age of twenty-nine, he became available for another post. Although he could always live in comfort at Glenlair, devoting his time to science and country life, it must have been a disappointment when he failed, even with the support of Faraday, to win the chair at Edinburgh recently vacated by the translation of his old teacher, J. D. Forbes, to the principalship of United College in St. Andrews.

However, on leaving Aberdeen Maxwell almost immediately stepped into the Chair of Natural Philosophy at King's College, London, where he spent five years. It was here, as a member of a British Association committee, that he did pioneer work in establishing standards for electrical units, but more important was his development of his theory of the electromagnetic field. In this he was stimulated not only by personal contact with Faraday, but by the papers of William Thomson, later Lord Kelvin. Thomson was Maxwell's senior by seven years. Like him he had been second wrangler at Cambridge, and at the age of twenty-two, in 1846, had been appointed Professor of Natural Philosophy at Glasgow, a post which he held for fifty-three years.

The particular idea that proved so fruitful in the work of Maxwell was that the essential actions of electricity and magnetism take place in a material medium pervading all space. The concept of an ether was, in fact, a very old one, being first brought into science by Descartes, who was born in 1596. In the time of Newton its chief exponent was Robert Hooke, who developed a theory of light as a vibratory motion of the ether. The idea had, however, been abandoned in the mathematical theories of electricity and electromagnetism developed on the Continent by Coulomb, Poisson, Ampère, Weber, Neumann and Ludwig Lorenz. It was, nevertheless, the basis of all Faraday's physical reasoning and was taken up by William Thomson. At the age of seventeen, when

a freshman at Cambridge, Thomson published a paper in which he compared the electrostatic field between charged conductors with the flow of heat in a solid. He showed that the surfaces of equal potential in the electric field correspond to isothermal surfaces, and that an electric charge corresponds to a source of heat. A few years later he extended Poisson's theory of magnetized bodies and, after applying it to polarized dielectrics, went on to develop the concepts of B and H, which are now something of a magnetic *pons asinorum* for students. In the same series of papers, published in 1851, he developed the theory of the energy stored in the magnetic field and the mutual energy of magnets and electric currents. All this, with Faraday's ideas, provided the foundation upon which Maxwell built.

In papers published in 1861 and 1862, in the *Philosophical Magazine*, Maxwell first expounded his dynamical theory of electromagnetism. It was entirely in terms of a material medium, and he supposed that in a magnetic field this medium is in rotation about the lines of force, each line being pictured as a separate vortex. In between these rotating vortices he imagined contiguous particles of electricity, like idle gears between gear wheels rotating in the same direction. So if two neighbouring vortices have the same circumferential velocity, the intervening particles merely rotate, but if one circumferential velocity is greater than the other the particles will have a translatory motion. He therefore identified the flux of these particles with an electric current.

The behaviour of this model, he showed, is described by the famous equations which bear his name. One of them gives the electric field induced when a magnetic field changes, but the essentially new phenomenon which Maxwell deduced from his model was the complimentary fact that a changing electric field must produce a magnetic field. He was led to this, it seems, by the explanation his model provided for an electric field. The magnetic cells were supposed to be highly elastic so that an electric stress would produce a strain by exerting forces on the intervening particles. Any change in the electric stress would then result in a change in the strain, this being interpreted as an electric current.

Thus Maxwell evolved the idea of the *displacement current*, which he supposed to exist in a complete vacuum whenever the electric field changes. He showed that when this concept is included every electric current can be considered to flow in a closed circuit. The combination of the two effects, an electric field from a changing magnetic field, and a magnetic field from a changing electric field, leads at once to equations of wave motion with the velocity of light. This, then, was Maxwell's great achievement. 'We can scarcely avoid the inference', he said, 'that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena.' In a paper to the Royal Society in 1864 Maxwell gave his theory a more mathematical form with less emphasis on the mechanical analogies, and his equations, if not his physical concepts, have survived unchanged to this day.

In 1865 he resigned the London chair and retired to his estate. A variety of reasons no doubt contributed to this step. It enabled him to devote more time to his original work; it undoubtedly pleased his wife, who was, it is feared, not sympathetic to science as a vocation for a gentleman; and King's College was not flourishing. Matthew Arnold called it a strangely devised and anomalous organization, and in 1875 it was so hard up that it was forced to sell its silver spoons. Maxwell now had the leisure to write his *Treatise on Electricity and Magnetism*, although this great work was not published until 1873, when for two years he had been Professor of Experimental Physics at Cambridge. His time in Cambridge was tragically short, for he died in 1879, after a long and painful illness, at the early age of forty-eight. He was buried in Scotland, in Parton Churchyard near Glenlair. His successor, Lord Rayleigh, later said that by his genius things were done at Cambridge which could hardly have been produced in any other way. In particular, he found Cambridge so saturated with the subject of electricity that he quickly decided to make it his own particular study.

Maxwell did not live to see the triumph of his theory, and it is sad to think of the untimely loss to British science of one who, a 'veray parfit gentil knight', might have lived well into our own century. Great honours and a title, doubtless, would have come to him, as in the fullness of time they came to many nurtured in the laboratory he built. As plain James Clerk Maxwell, Esquire, he is one of the immortals of science.

The establishment of the Cambridge chair in 1871, by the Duke of Devonshire, was a major step in the great movement of about a century ago to establish scientific education in Britain. A leader in this movement was Lyon Playfair, a gifted and energetic son of St. Andrews, who in 1892 became Baron Playfair of St. Andrews. As Professor of Chemistry in the new School of Mines in London in 1851, he gave two inaugural addresses which had great influence. In the first he stressed the necessity of coupling the advance of pure science with industrial progress. If this was not done, then, in his own words, 'as surely as darkness follows the setting of the sun, so surely will England recede as a manufacturing nation, unless her industrial population become much more conversant with science than they are now'. He gave his second lecture in 1852, after a first-hand study of Continental technical education. Again he stressed the vital importance of harnessing science to industry if Britain was to survive. No longer could we count on abundant and cheap natural resources: in the future the race would go to those who had the greatest scientific skill. He spoke of 'our overweening respect for practice and contempt for science'. We had 'eminent practical men and eminent scientific men but they generally walk in paths wholly distinct, and there is often a want of mutual esteem and a misapprehension of their relative importance to one another'. It is ironical to note that fifty-six years later, when a Royal Commission was reporting on Imperial College and London University,

our deficiencies in technical education were still blamed for the lack of co-ordination between science and industry.

Some progress was made, but it was too little and too slow. The whole social climate was adverse not only to educated technology but to science itself. Secondary and university education were gripped in the vice of the classical tradition. However, here and there the voice of the rebel was heard. For example, Mark Pattison, Rector of Lincoln College, Oxford, published in 1868 a book advocating the redistribution of the University endowments to enable Oxford to become a scientific institution. Although Pattison's book failed to cause a revolution in Oxford, it aroused much interest since it appeared just at the time when the Government had again been roused by Lyon Playfair. The great International Exhibition in Paris in 1867 had exposed once more the serious shortcomings of British industry, and Playfair started a discussion in which the proposal was made that a technical university should be formed from the colleges in South Kensington. The Society of Arts then organized a conference, in 1868, in which Playfair took a leading part, stressing the need for new beginnings. He felt that Oxford and Cambridge could do little, since the public-school boys who went there were ignorant of science. The Society's committee afterwards submitted a report proposing the foundation of colleges of liberal science, and pointing out the great need for improving general secondary education with the inclusion of science. Playfair's view was that secondary education must be made available to all and that there should be adequate scholarships for entry to the liberal science colleges. The British Association then entered the picture, when, in 1868, Colonel Alexander Strange read a paper *On the Necessity for State Intervention to Secure the Progress of Physical Science*, in which he advocated the foundation of Government research institutions. It is evident that Playfair and Strange were among the first who saw the necessity for true applied science. The result of all this was the appointment, in 1872, of a Royal Commission with the Duke of Devonshire as chairman. This commission, which included Kelvin, supported the need for State research laboratories and the reform of secondary education. It also recommended that the education of scientists should include cultural studies, and *also* that a classical education should include some science.

If the Government had supported these recommendations with hard cash, our present national economy might well be less precarious. In 1879 we find Silvanus P. Thompson saying: 'there is no question whatever but that the persistent neglect of technical education in England will sooner or later ruin her in the markets of the world'. It was not that technical education in Britain did not exist. It did exist, particularly in Scotland, as is clearly shown by the history of the great Scottish technical colleges, but it was regarded as suitable only for artisans. Glasgow University, it is true, got a chair in engineering in mid-century and Edinburgh followed in 1868, but even two swallows do not make a summer. The fault was that neither technical nor scientific education was woven into the stuff of the national culture, and that far too few in the traditionally educated ranks of government and higher education had the knowledge, or foresight, to understand why it should be.

The close linking of pure and applied science in universities with a cultural foundation, as advocated by Playfair, did not therefore take place. What in fact happened was the development of pure science in the universities on increasingly specialized lines, a similar specialization of engineering in a very few universities, and the growth of technical education in separate colleges. As a result the universities are now faced with a problem whose solution was clearly prescribed by Playfair in 1873. On 8th February of that year he addressed the St. Andrews Graduates Association on *Universities in their Relation to Professional Education*. He pointed out that the early European universities grew out of professional schools, for example Salerno from medicine and Bologna from law. They were essentially places of training for the learned professions of the time. Gradually the faculties of arts developed, first as preparatory schools for the professional system, and ultimately gained the ascendancy. In the University of Paris there was, in fact, a statute requiring students to refrain from passing through the Faculty of Arts until they were twelve years old. The main object for which universities were founded, said Playfair, was to liberalize the professions. It is, he said, the power of liberalizing the professions that distinguishes universities from technical schools. In the early constitutions of our own universities the Faculty of Arts was the preparatory school of the priest, the lawyer, and the doctor, but later at Oxford and Cambridge professional teaching became subordinate to Arts. The inference, of course, is that if the universities are to revive their original purpose they must include the new professions as well as the old. One passage is worth quoting in full:

> If liberal culture be, as it should be, a part of professional training, then the culture should be made to bear directly on the training, and not remain a mere survival of an educational condition that is known only to us in history. New professions are arising around, but for these our old universities make no provisions. Perhaps the most robust men of our time have been our engineers and mechanicians, for they have given more impulse to civilization than any other class of men. But I look in vain for a single representative man among our Telfords, Watts, Stephensons, Arkwrights, Wedgwoods, whose intellect was nurtured on ancient classical learning, or who could find anything in school life to aid the development of their genius. I look in vain among our scientific heroes—among our Newtons, Daltons, Youngs, Davys, Brewsters, Faradays—for one who owed the cultivation of his intellect to classical education . . . and yet our Prime Minister, Mr. Gladstone, and Home Secretary, Mr. Bruce, make orations on the same day, telling us that the old classical system is best fitted for mental culture, under all conditions.

I have mentioned that the engineering chair at Edinburgh was founded in 1868. It was, in fact, founded by Sir David Baxter, a linen manufacturer of Dundee and a pioneer of the power loom. It was his brother and sister, John and Mary Ann, who later founded University

College in Dundee. The first Edinburgh professor was Fleeming Jenkin, an electrical engineer who worked on submarine cables and telegraphy with Kelvin. In 1873 he published a textbook on electricity and magnetism, and in 1885 the eighth edition, of nearly 400 pages, was selling at three shillings and sixpence. Now Mary Ann Baxter had endowed a scholarship for a student of Dundee High School to study engineering at Edinburgh, and the first scholar, who entered the university in 1871 at the age of sixteen, was James Alfred Ewing.

Ewing, a son of the manse, did well at Edinburgh in both engineering and natural philosophy. In the summers he worked on submarine cables, travelling as far as Brazil and the River Plate, and at Jenkin's home he made a friend in Robert Louis Stevenson. On Jenkin's nomination he went to Tokyo at the age of twenty-three as Professor of Mechanical Engineering, and it was there that he started his work in magnetism and married a great-grandniece of George Washington.

After four years in Japan he was ready to return home. His brother told him of the new University College in Dundee, in which engineering was to be one of the four chairs. Ewing applied, was appointed on the 21st November 1882, and arrived in Dundee in the following year. At first his facilities were poor, but he quickly organized a comprehensive course which included an excellent syllabus in electrical engineering. In 1888 he moved into new laboratories in what we still call the Technical Institute. Sir David Baxter had left money to found a Mechanics' Institute in Dundee, but the sum available was not enough. The trustees therefore joined with University College in financing this building and it served a dual purpose until 1909, when the present Technical College in Bell Street was completed. Ewing's own room was part of what is now our staff common room, and the present college hall was the engineering laboratory.

Ewing's broad education enabled him to put into practice what had been advocated by Playfair thirty years before. In him the paths of eminent practical and scientific men not only converged but met. In later years he wrote of the engineers of the mid-nineteenth century: 'They were sagacious men who put their faith in experience: they knew little of theory and cared less'. Dundee, with a tragic experience of engineering without science so fresh in its memory, could well agree that it was time for a change. To the Institute of Physics, in 1922, Ewing said: 'As the art of engineering progresses, it becomes more and more true that the impulses towards any new departure are in general given by men who are physicists as well as engineers, who are at home in that delightful country which may be described as the borderland of physics and engineering'. This was the man who, after seven busy years in Dundee, went to Cambridge and founded the Engineering Laboratory and the Mechanical Sciences Tripos. It may, indeed, be said that Ewing, by his work in Cambridge, set the stamp on university engineering education in Britain for many years.

During the Cambridge period he published three of his books: *Magnetic Induction in Iron and other Metals*, in 1891; *The Steam Engine and other Heat Engines*, in 1894, and *The Strength of Materials*, in 1895. All proved to be classics, and the diversity of their titles testifies to the breadth of his interests. He left Cambridge in 1903, at the call of Admiral Fisher, to become Director of Naval Education at the princely salary (in those days) of £2 500 with a free house. He stayed at the Admiralty for fourteen years, but when war broke out his educational work was disrupted and he was asked to deal with enemy ciphers. Soon, under the Director of Naval Intelligence, Admiral Hall, he became head of the famous 'Room 40'. In 1917 he was appointed Principal and Vice-Chancellor of Edinburgh University, a post he held with distinction until his retirement to Cambridge in 1929. There he died six years later, and we honour his memory in the Ewing Building in Queen's College.

There is one more Victorian of whom I must speak, who, although educated in the classical tradition, saw so clearly the dangers to the British economy arising from the neglect of science and a one-sided philosophy of education. This was Matthew Arnold, son of the great Head of Rugby who moulded the pattern of the English public schools. He is, perhaps, best known as a meditative and accomplished poet, but he earned his living for over thirty years as an efficient Inspector of Schools. This did not prevent him from holding, for ten years during the same period, the chair of poetry at Oxford, or from making his name as a critic, always in beautiful prose, of Church and society. In his capacity as Inspector of Schools he made a detailed study of education on the Continent, and in 1868 published his findings and comments in his book *Schools and Universities on the Continent*. It was in the schools and universities of Germany that he found the most valuable lessons for Britain's guidance. In particular, he found that science played an integral part in the education of the German middle, professional class. Such was not the case in Britain, and the deficiency was not made up in the rudimentary education of the artisan and working classes, who knew no science. He deplored the division of the 'whole circle of knowledge' into two disconnected parts, one the province of the 'humanists', the products of the public schools and the ancient universities, and the other of the 'realists', the new men who were pushing, albeit with great difficulty, the cause of science. He believed in the great value of the study of the achievements of Greece in literature and the arts, particularly during the two centuries from the birth of Simonides to the death of Plato. He wrote:

> It is a vital and formative knowledge to know the most powerful manifestations of the human spirit's activity, for the knowledge of them greatly feeds and quickens our own activity; and they are very imperfectly known without knowing ancient Greece and Rome. But it is also a vital and formative knowledge to know the world, the laws which govern nature, and man as a part of nature.

Instead of education embracing the whole, however:

> the humanists are loth to believe that man has any access to vital knowledge except by knowing himself,—the poetry, philosophy,

history which his spirit has created; the realists, that he has any access except by knowing the world,—the physical sciences, the phenomena and laws of Nature. . . . But it seems to me that so long as the realists persist in cutting in two the circle of knowledge, so long do they leave for practical purposes the better portion to their rivals, and in the Government of human affairs their rivals will beat them. The men who have had the humanistic training have played, and yet play, so prominent a part in human affairs, in spite of their prodigious ignorance of the universe, because their training has powerfully fomented the human force in them.

And so it has proved, even to this day. How many scientists or engineers are there in the Cabinet, or, for that matter, in Parliament?

Why, one may well ask, did not Matthew Arnold's view, so obviously right, bear more fruit? Unfortunately his father, Thomas of Rugby, had died long before at the early age of forty-seven. Had he lived, his mind might well have been further illumined by his brilliant son. As it was, and as so often happens, Thomas's work, progressive and provocative in his day, crystallized into reverent dogma after his death. Many of his followers, so far from seeing a circle of knowledge, progressed little in science beyond the belief that the earth is flat. Not until our own times has science come into its own in the public schools. Now, I am told, about half the sixth form is specializing in science and mathematics.

Specializing—not the whole circle of knowledge: why, if the Sons of Mary had no cause to change their confident, half-ignorant, dominant way, did not the Sons of Martha complete the circle? The answer is to be found, I think, largely in the social pattern and fabric of British society and industry, but also partly in the fact that university education in the past century gradually became more specialized in all faculties, even in arts. This may have been due to German influence, but another cause may have been the exigencies of the examination system. Early plans for scientific curricula did, in fact, contain provision for broad cultural studies, but these were gradually pushed out by expanding scientific syllabuses and the economic value of the specialized honours degree.

The salaried engineer or scientist, in those days, had little chance of rising to high administrative office in industry. He therefore regarded any study of the humanities not only as a waste of time but as a positive obstacle to his attaining greater proficiency in his speciality. Further, a salaried engineer with a university degree was not likely, in industry, to be given much opportunity of entering into professional human relations. In the factory itself human relations were the province of the practically trained men who had risen 'the hard way', with a healthy scorn for theory and book learning. Neither were his services required on the higher planes of finance, policy, commerce and administration. He was, in fact, a 'back-room boy' who sold his specialized knowledge and experience and nothing else. He dealt with things, not men.

There was really very little necessity to change this state of affairs while Britain enjoyed industrial pre-eminence and world power. One can always win a race if one has enough start. Lesser countries, like Germany and the United States, no doubt had to do things differently, for they were trying to catch up. The Massachusetts Institute of Technology, founded in 1864, set out from the beginning to train men for posts in which 'a systematic study of political and social relations and familiarity with scientific methods and processes are alike essential'. The technical universities on the Continent have, likewise, always recognized that their graduates were potential managers and directors, and educated them accordingly. Now, at last, this necessity is recognized in Britain.

In the latest Great Debate on technological education, the emphasis at first was almost entirely on the need for more technologists. Produce more specialists and all would be well: the Sons of Mary would tell them what to do. Fortunately the superficial nature of this prescription is now being realized. Britain cannot survive as an economically stable industrial power unless its industry is directed and administered by the professionally competent. The appearance of the pomp and panoply of power cannot long be maintained without the substance. What is needed is a complete change in the traditional social attitude to careers in applied science and industry, but this will not be achieved unless we cease to think that all the best engineers must be educated as technical specialists.

Engineering education, therefore, must be broadened and liberalized, and this is the great challenge which faces the engineering faculties in universities to-day. The universities, by their very nature, have the means and opportunity of achieving this aim far more effectively than separate technological universities or institutes, important as these are and always must be. In the universities we have, ready to our hand, the departments in sociology and the humanities by whose co-operation we must, and can, achieve a synthesis of the basic knowledge of human society and human relations required by our graduates if they are to play a full part in improving our industrial efficiency.

We are undoubtedly undergoing a major social revolution. The old class distinctions between the so-called learned professions and the profession of earning the country's living in industry are disappearing, if slowly, but with their disappearance we must be sure that we do not lose the treasure of the old culture. We must build, and maintain unbroken, the whole circle of knowledge, and a large share of the responsibility for this must fall to the engineer and technologist.

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Features of New Power Stations in South Wales

621.311.22

The Chairman's Address to the Western Supply Group

We print here the Address which Mr. Priest gave in Cardiff on the 21st October 1957 as Chairman of the Western Supply Group of The Institution. The text has been slightly amended for publication. Mr. Priest was formerly Chief Generation Engineer (Construction) of the South Wales Division of the Central Electricity Generating Board. He is now Chief Project Engineer for the Northern Area of the Board.

C. W. A. PRIEST, B.SC.(ENG.), MEMBER

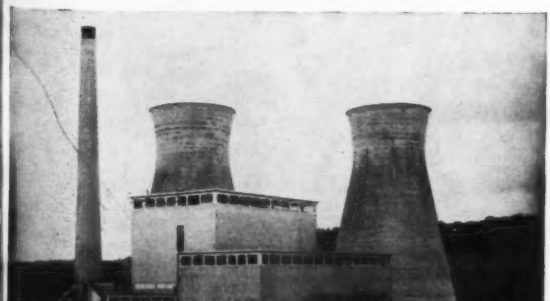
LAST year saw the commissioning of the sixth and final turbo-alternator in each of Uskmouth and Carmarthen Bay power stations, bringing the capacity of Uskmouth to 360 MW and that of Carmarthen Bay to 345 MW. The newest station in the South Wales Division is Rogerstone, where the first of its two 60 MW units was put on load last month. Of the two stations not yet in service, that at Aberthaw is getting well ahead with the foundation and marine works, allowing the first of its six 100 MW units to go in service by the end of 1959. Field work on the new Uskmouth 'B' station has only just begun, with the aim of commissioning in 1960 the first of its three 120 MW sets.

These five power stations together will contain 1785 MW, or nearly $2{\cdot}5 \times 10^6$ h.p., of electrical generating plant, costing around £100×10^6, and the plant is of the latest type available. Naturally there have been many problems in both design and construction stages in civil, mechanical and electrical engineering—often unusual problems which have provided the opportunity of finding unusual solutions, and it is this aspect of the new technique or unusual solution which is the core of my talk this evening. I propose to high-light just a few examples of such solutions, some used for the first time in power station construction in South Wales, and some for the first time in Britain.

Foundations

It will be understood that one, but only one, of the major factors influencing the selection and design of a station, is the cost of making the ground suitable for carrying the very heavy loads to be imposed upon it. Seldom is it possible to find good solid rock close to the surface of an area otherwise suitable, but at Aberthaw there is a large sector where limestone rock of great depth forms a fairly level layer only 25 ft or so below the ground level. It was possible there to excavate the overlying clay and sand and to found the heavy boilers and turbo-alternators directly on the rock, and to place the condensers and much of the auxiliary plant in the basement formed by that excavation. The basement floor being below high tide and ground water levels, a retaining wall was necessary around the whole excavation, lighter structures outside this area being supported on short concrete piles bearing directly on the rock. At Uskmouth, ground conditions are very different, no rock being available at practical depths. The 'A' station was therefore founded on the marl, at a depth of 35–70 ft below the surface. The 'A' station required 9250 reinforced concrete piles to be made and driven, and the 'B' will require another 4000, each 70 ft long and 18 by 16 in. in section.

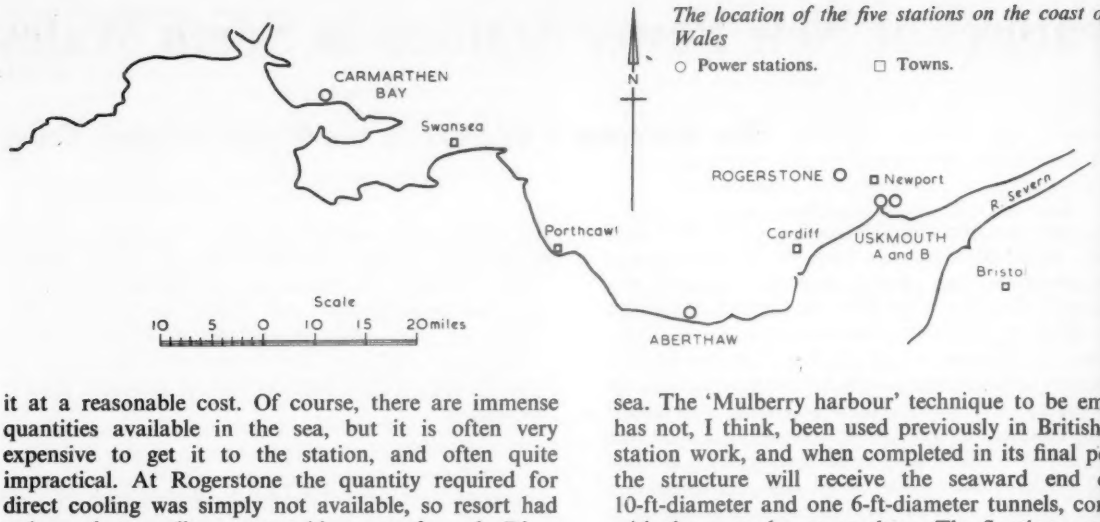
Rogerstone station, containing two units of 60 MW each, with aluminium panels on the superstructure above operating level



But occasionally the site of a station is on ground of glacial origin, as in the valley at Rogerstone. There is rock there, and only 40–50 ft down, but the overlying clay and sand is thickly interspersed with quite large boulders, typical of glacial background, which renders the more usual piling methods very difficult. The solution favoured the Benoto system, which applies well-boring technique to piling, forming mass concrete columns a metre in diameter to stand a test load of 400 tons a pile. Two boring rigs had to be brought over from France, and the very ingenious mechanization of the boring rig saved much time and money at Rogerstone, where it was used for the first time for a British power station.

Cooling Water

Now I turn to another problem, that of getting the large supplies of circulating water required, and of getting



The location of the five stations on the coast of South Wales

○ Power stations. □ Towns.

it at a reasonable cost. Of course, there are immense quantities available in the sea, but it is often very expensive to get it to the station, and often quite impractical. At Rogerstone the quantity required for direct cooling was simply not available, so resort had to be made to cooling towers taking water from the River Ebbw to make up losses in the towers. The problem here is the state of the water, which contains much solid matter, including trade wastes, and a chemical purification plant had to be provided, even making provision for the automatic stopping of the intake pumps where there was evidence of acidity in the water.

At Uskmouth direct cooling was quite possible, and only became a problem at low spring tides when the level of water in the estuary fell disconcertingly, and the heated return water was deliberately passed into the estuary upstream of the inlet so as to augment the flow past the inlet to the station at low spring tides. But the River Usk has a rise and fall of over 40 ft, and the construction of the pump-house and riverside intake was a major civil engineering feat, in very difficult ground.

The design required the sinking of a caisson, 164 ft by 110 ft in plan and 80 ft deep, into which pumps, motors, pipes and screens would be fitted later. A steel caisson shoe, weighing 510 tons, was erected on shore on ball carriages, run out riverwards into position, and lowered on to a strengthened foreshore by hydraulic jacks. With work under compressed air, excavation inside the caisson allowed the whole to fall slowly to the required depth as the walls were being built up. Having a total weight exceeding 42 000 tons, this caisson is believed to be the largest in the world sunk under compressed air.

The ideal of unlimited supplies of cool water close inshore was most nearly approached at Aberthaw, although it was necessary to go out to sea nearly half a mile to be sure of those supplies at all states of the tide or weather. Apart from the much-appreciated facility of being able to tunnel in rock all the way, the unusual feature at Aberthaw will be the intake structure, taking the form of a circular concrete island 95 ft in diameter, which will be constructed on shore above the high-tide mark. After temporarily making it watertight, it will be launched and towed out to sea, to be sunk on a shelf of fairly flat rock already selected and about half a mile to sea. The 'Mulberry harbour' technique to be employed has not, I think, been used previously in British power station work, and when completed in its final position the structure will receive the seaward end of two 10-ft-diameter and one 6-ft-diameter tunnels, connected with the pump-house on shore. The floating out should take place in the summer of 1958.

A demountable lifting gantry raising No. 1 alternator from a road vehicle onto the foundation block at Rogerstone

Buildings and Main Plant

Power station buildings have had more than their fair share of criticism, ranging from comment of 'industrial cathedrals' to just 'ugly'. Others have suggested that money is being wasted in beautiful brick buildings when some form of sheeting would be sufficient, cheaper and even more beautiful. So whilst both Aberthaw and Uskmouth 'B' are to be brick clad because of their positions on an exposed coastline, an excursion into sheet aluminium has been tried at Rogerstone. Aluminium is also being used as a coal conveyor cladding at Aberthaw in a position where it is bound to receive much sea salt spray, but modern aluminium alloys should resist this quite well.

Two years ago in his Chairman's Address to the Western Supply Group Mr. E. K. Wood spoke of the great and increasing difficulties of transporting the larger and heavier pieces of plant from the maker's works to the power stations. There is an example at Rogerstone which will emphasize his point. Each of the electrical stators, weighing over 100 tons apiece, was taken by road from the factory at Hebburn on Tyne and loaded into ship at Newcastle for shipment to Cardiff. The only crane on the South Wales coast capable of unloading this weight back onto a road vehicle was the harbour authority's floating crane of 100 tons capacity, which was therefore pressed into service.

And the unloading at Rogerstone was also complicated, for another idea had been put into practice there. For years station engineers have been troubled by the necessity of installing a turbine-house crane capable of handling the alternator stator, with the knowledge that that stator is most unlikely to be handled in one piece again. And the next heaviest lift required in service is generally less than half the weight of the stator. The cost of the heavier crane, with its proportionate costs of crane gantry, structural steel support and foundations, might run to £50,000 or so for a six-set station, and engineers have tried to devise means of saving that money. At Rogerstone a special demountable gantry was designed and used for unloading both stators, and although the final costs did not show all the savings anticipated, no doubt there will be new designs which may do better.

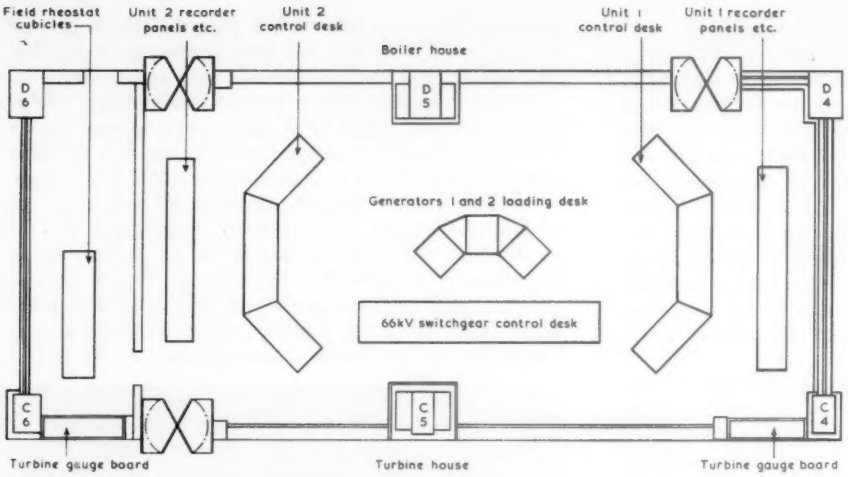
Of course every station engineer knows that the effort to increase the operating steam pressure and temperature is simply another phase of the search for ever-increasing efficiency and coal economy, affecting the cost of generating electricity. It may not be so well known that, in general, increased capacity of individual units also helps to keep down the overall cost of generation, by holding down the cost of installation. But increased size of unit plus increased steam pressure necessitates increased temperature if the whole economy possible is to be obtained, and therein lies a difficulty, for maximum permissible metal temperatures have not kept pace with size and pressure. The problem is not new, for it was there before many of our present alloy steels came into general use, and in the nineteen-twenties it was solved at one station on the north-east coast by reheating the steam after it had passed through part of the turbine. The system has been revived since the last war, and is being applied to most larger sets to-day.

The first new stations on the 900 lb/in.² (gauge) 900° F steam operating range went into service as recently as 1950; yet possibly Rogerstone will be the last in these parts to have 60 MW machines on the '900–900' range. Aberthaw with its 100 MW turbines will use steam at 1 500 lb/in.² (gauge) and an initial temperature of 975° at the stop valve. Reheating is to be applied when the steam has expanded down to 432 lb/in.² (gauge) and the temperature raised from 683 to 950 degrees before re-entering the machine. The 120 MW units at Uskmouth 'B' will operate at a pressure of 1 500 lb/in.²

Uskmouth 'A' station, with six 60 MW turbo-alternators and twelve 300 klb/h boilers

(gauge) and a temperature of 1 000° F at the turbine stop valve, reheating to 975° F, and it is expected that the thermal efficiency sent out will be raised to 35·1%.

The adoption of larger turbines and boilers highlights the cost of suitable valves, pipe-lines, receivers, etc., and most modern stations, including Rogerstone, Aberthaw and Uskmouth, have been designed on the 'unit system', in which one boiler is connected to only one turbine, thereby allowing significant savings in the pipework and valve costs. Of course, such a system puts a high premium on the ability to avoid breakdowns and unplanned outages, and it is a tribute to modern design and maintenance that the 'unit system' is considered a justifiable commercial risk. Naturally, the adoption of a unit system leads to the collection of control instruments for both turbine and boiler at a single point, and possibly to the grouping of two such units at each control point. At Rogerstone, with only two boilers and two turbo-alternators for the complete station, the single control point was clearly 'on'. But the chance was offered also of including the whole of the normal electrical control room with the unit controls, so at this station there is no



The layout of Rogerstone control room

At this two-set station the boiler, turbine and switchgear controls have been grouped within a single central control room.

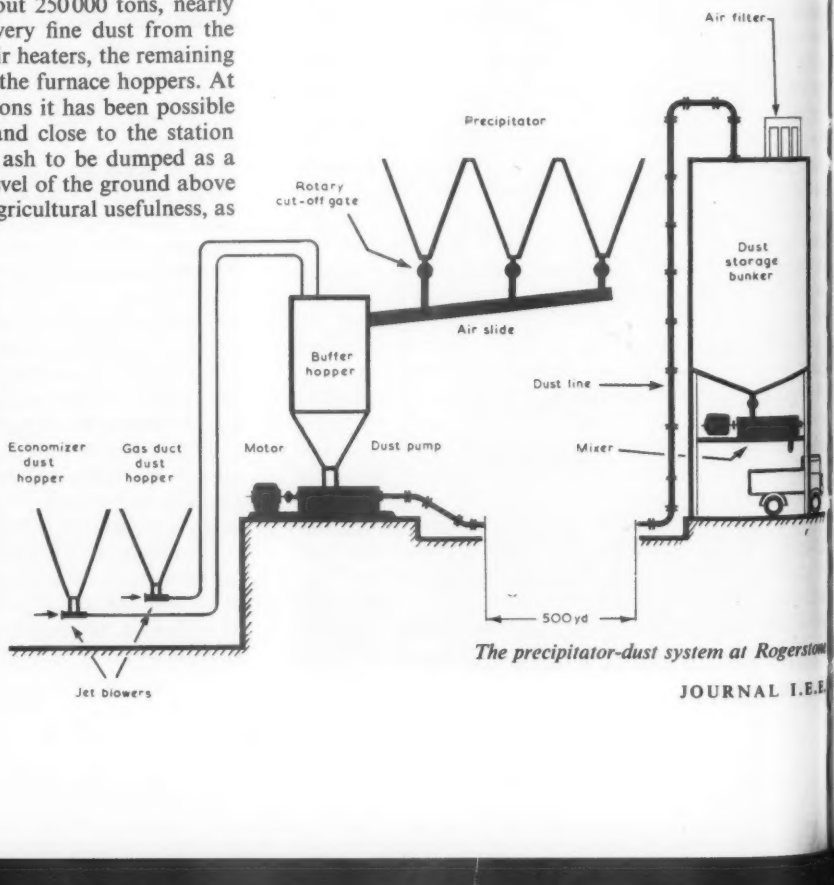
control room in the normal accepted sense, and all operating instrumentation for boilers, turbines, switchgear and synchronizing is in one room located midway between turbines and boilers on the operating floor.

Ash handling

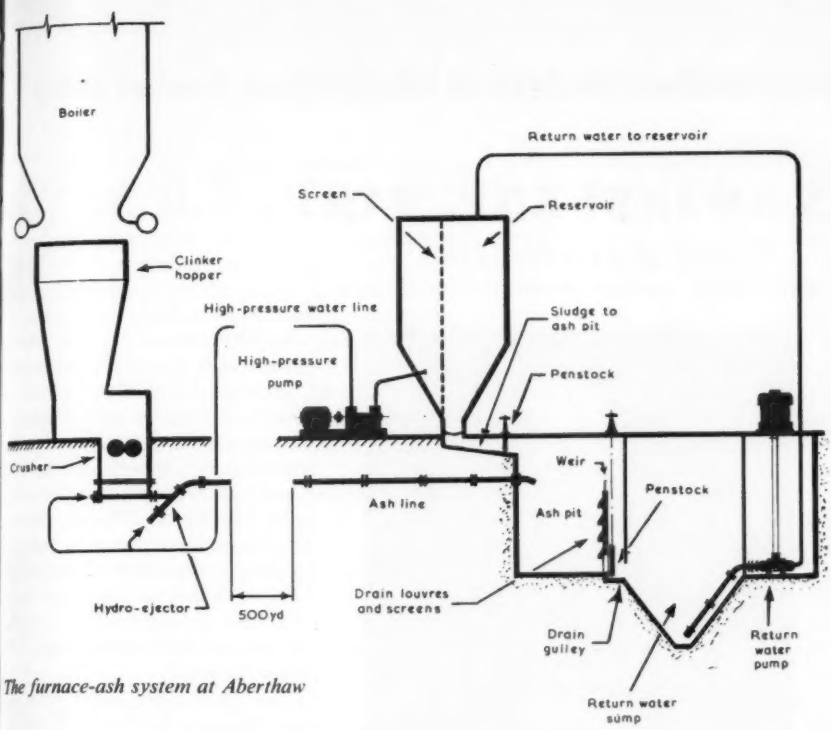
All new coal-burning stations are designed to consume pulverized fuel, and the ash from such stations always provides a handling and disposal problem. Intensive efforts are being made to find a market for it as a cement or sand substitute in mass concrete, or in the making of bricks and blocks; yet at present the material must be treated as a trade waste. At Aberthaw, for instance, the peak coal consumption is estimated at $1{\cdot}4 \times 10^6$ tons a year, giving an ash make of about 250000 tons, nearly 200000 tons of which will be very fine dust from the precipitators, economizers and air heaters, the remaining 50000 tons a year coming from the furnace hoppers. At all of the new South Wales stations it has been possible to find marginal or floodable land close to the station and of sufficient acreage for the ash to be dumped as a filler; this effectively raises the level of the ground above flood level, thus improving its agricultural usefulness, as demonstrated at Uskmouth.

But if a market in pulverized fuel ash materializes, it will be necessary to offer the ash in the condition required by the user, and this may demand dry ash, unpolluted by sea or soil, or it may have to be wetted to a stated figure. Partly for this reason and partly for reduced maintenance costs, it has been decided, at Rogerstone and the two later stations, to provide complete separation between the precipitator-dust system and the furnace ash system; the former will be handled dry by pneumatic means right up to the main collecting hoppers, involving pneumatic dust pumps and air-slides. Each hopper outlet has a mixer conveyor to permit any desired proportion of moisture being added to the dust for transport or bagging.

At Aberthaw and Uskmouth 'B' an effort is being made to get away from the usual ash sluice in the boiler basement to discharge the furnace ash. At these two stations, each boiler will be treated as a separate unit with its own collecting and crushing point, from which the furnace ash will be moved by hydro-ejectors through pipes to a collecting pit outside the station. It is not anticipated that the crushers will be heavily loaded, although one is



The precipitator-dust system at Rogerstone



The furnace-ash system at Aberthaw

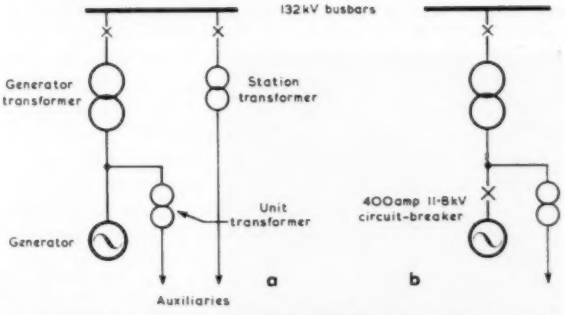
provided for each boiler, since the furnace design excludes all refractories and cast iron blocks.

Auxiliary Plant

The larger turbine and boiler capacities now coming into use bring with them some difficulties with auxiliary plant, especially in relation to motor sizes, which may be high-lighted by a reference to feed pumps, where the usual arrangement now is to provide pumps of 100% full-load duty, with duplicate pumps as standby. For reasons of both economy and size, it has been decided to split the pressure lift between de-aerator and boiler feed between two separate pumps operating in series without any intermediate surge or pressure-head device. And as a compromise between hydraulic, mechanical and economic limitations, the two pumps are to be switched together, with squirrel-cage motors and direct-on-line starting. As the feed-pump motors at Uskmouth 'B' will be 2650 h.p. working in series with booster pumps of 1000 h.p., one can well appreciate the repercussions on the auxiliary system voltage. And whilst the feed pumps have the largest auxiliary motors, induced draught fans, pulverizing mills, etc., have motors of no mean size. The Aberthaw auxiliary electrical system main voltage has been stepped up to 6·6 kV and the primary switchgear will be rated at 250 MVA.

An unusual electrical arrangement is being installed at Uskmouth 'A' station. The alternators, generating at 11·8 kV, feed directly into the step-up transformers, and switching is at 132 kV, in what has become the standard connection. The unit transformer is supplied from the 11·8 kV terminals of the main transformer. Transmission studies indicate, however, that in two years or so it will be essential to be able to operate the 'A' station split between two 132 kV transmission rings, with an appreciable phase displacement between them. The problem really boiled down to whether the auxiliary systems could still be supplied from the existing house transformers without danger of paralleling the two 132 kV networks through the 3·3 kV gear. Finally it was decided to select three of the six alternators to do duty on the eastern transmission ring, and to make them independent of the station auxiliary system by inserting an oil circuit-breaker between the alternator and the step-up transformer. The unit transformer may then be energized from the 132 kV supply whilst the alternator is at rest and the 11·8 kV switch open. Synchronizing is carried out on this switch, but all fault clearances must be made on the 132 kV end. The arrangement has been tried before, notably at Meaford with 30 MW machines, but I think that this is the first time it has been used on larger sets, for at Uskmouth it will involve a circuit-breaker with a continuous current carrying capacity of 4000 amp.

I hope I have been able to show that the design and building of even a conventional power station still provides immense interest and technical excitement for those engaged in the work. There has been enormous progress made in the 34 years I have been 'in power stations', but I am sure that the next 30 years should prove even more stimulating.



The interposition of an 11·8 kV 4000 amp continuously rated overload circuit-breaker for synchronizing only. This permits the unit auxiliaries to be energized without the use of a station transformer

a The usual connection.
b Arrangement a adapted to three sets at the Uskmouth 'B' station.

An outstanding centenary: Sir James Swinburne completes one hundred years

SIR JAMES SWINBURNE, BART., F.R.S.

BORN 28TH FEBRUARY 1858

PRESIDENT OF THE INSTITUTION IN 1902

SIR JAMES SWINBURNE, BART., F.R.S., MEMBER, who was President of The Institution fifty-six years ago, celebrated his 100th birthday on the 28th February. This striking event, which will please members of The Institution throughout the world, is believed to be unique in the sense that there is no record of any other distinguished engineer reaching the age of 100. The Council have sent a letter of congratulations to Sir James, which was delivered personally to him on his birthday by Dr. W. H. Eccles, and the President spoke with warmth about him at the Annual Dinner, when his health was drunk. He has been a Member of The Institution since 1885—a period of Corporate Membership of 73 years, which has never been equalled.

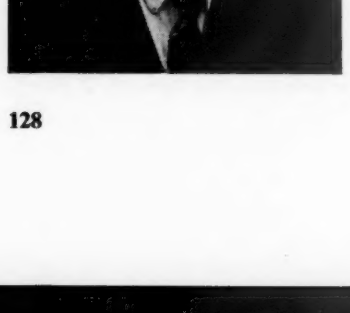
Sir James was educated at Clifton. He gained electrical experience in Swan's lamp factory in Newcastle and helped to start other lamp factories abroad. For a period he was manager of Crompton's dynamo works, and at this time he invented his 'hedgehog' transformer and a watt-hour meter. He was in practice as a consulting engineer for several years and acted as an expert witness.

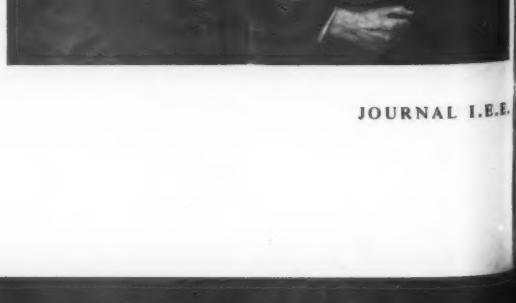
A portrait of Sir James by the late T. C. Dugdale, R.A., painted six years ago. It hangs in the Board Room of Bakelite Ltd., and is reproduced here, as are the photographs below, by permission of the company.

In 1902 began a long association with the development of phenol-formaldehyde resins in this country; the first substance that he experimented with was humorously registered as 'Damard lacquer'—a typical Swinburnian witticism for he has for long been famous for his sense of humour. He is at present Honorary President of Bakelite Ltd., of which company he was Chairman for many years. In 1906 he was elected a Fellow of the Royal Society.

Last month Sir James sent a message of good wishes to members of The Institution. He added jokingly, 'I was very young indeed when I was made President. I took myself very seriously and was very solemn, and I got on very well.'

Sir James is still in good health and often goes for a walk—without a coat! It is good to know that he does not suffer at all from any form of rheumatism. He has talked vividly about old days to several visitors who have called on him recently at his home in Bournemouth. There he and Lady Swinburne, who is some ten years younger than him, live graciously in their retirement, after sixty years of married life.





Two photographs of Sir James and Lady Swinburne taken last month in the garden of their house in Bournemouth.

620.92 NUCLEAR ENERGY IN THE SERVICE OF MAN

During the 1956–57 session of The Institution, Dr. Allibone gave a highly successful Faraday Lecture on nuclear energy in London and various Local Centres. A shortened version of it was televised, and a telefilm recording of this has preserved the lecture in permanent form. The article that appears here is founded on the Faraday Lecture and bears the same title. But it is of course addressed to the electrical engineer rather than the layman, and thus discussion of elementary scientific facts has been omitted. The technical content is also rather fuller than that of the original lecture.

In this effective and readable survey of the peaceful applications of nuclear energy, Dr. Allibone ranges from neutron affinity of uranium to deuterium fusion reactions, from Fermi's early reactor at Chicago to the new fast reactor inside Dounreay's great steel sphere, from caesium as a source of γ-rays to the study of wear in a piston ring by tracer elements. This is indeed an article to fill in the gaps in most electrical engineers' knowledge of the present and possible future applications of nuclear reactions to civilian life. It stems from the author's great experience as a nuclear physicist and as Director of the Associated Electrical Industries' Research Laboratories at Aldermaston—where he has been responsible, among other nuclear energy research, for work on Sceptre, the experimental fusion reactor, which has proved as successful as Zeta, its bigger and better-known cousin at Harwell. Dr. Allibone also gave the 1945–46 Faraday Lecture on Atoms, Electrons and Engineers.

T. E. ALLIBONE, D.SC., PH.D., F.R.S., MEMBER

FISSION of the uranium nucleus by neutron bombardment was discovered by Hahn and Strassmann in 1939. Not only was the energy released at fission twenty times greater than that released by any of the radioactive elements upon emission of α-particles; far more important was the fact that at fission two or three neutrons are released with considerable energy so that, if they in turn bombard neighbouring uranium nuclei in a piece of metal and cause further fission, a chain reaction is started which can spread throughout the mass of uranium and release enormous amounts of energy. No such chain reaction had been discovered in any of the artificial disintegrations which were studied prior to the discovery of fission. By December 1942 a controlled chain reaction in a large mass of uranium had been achieved by Fermi in Chicago, and by July 1945 an explosive chain reaction had been achieved in Alamogordo, New Mexico.

Uranium Isotopes and the Fission Process

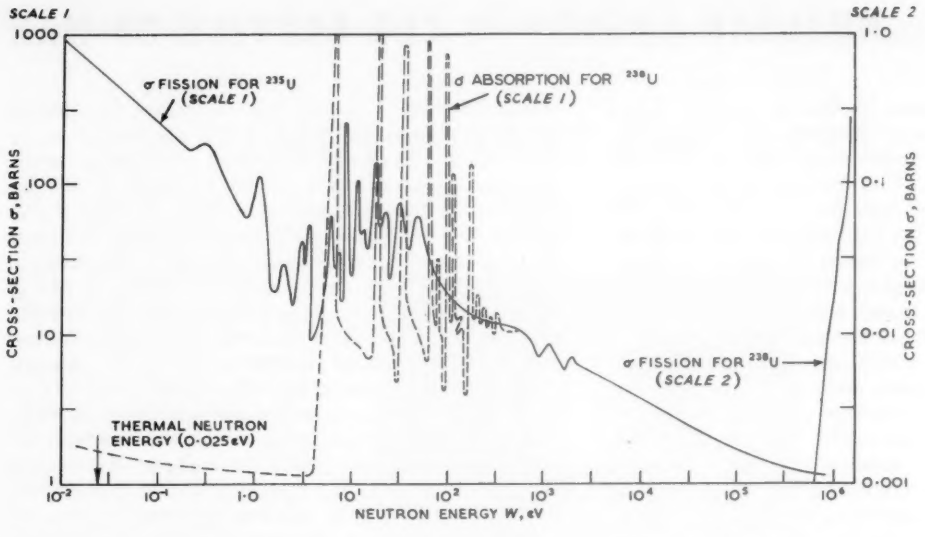
There are two isotopes of uranium, ^{235}U and ^{238}U, occurring in nature in the ratio of 1 : 140. It is the light isotope which generally undergoes fission whether bombarded by fast or by slow neutrons. The uranium 238 is more stable, and can disintegrate by fission only if the energy of the bombarding neutron is very high (in excess of 1 MeV); neutrons having lower energy are merely captured by the uranium 238 nucleus to form the isotope uranium 239. This is not fissile, but it undergoes a β-radioactive disintegration releasing a negligible amount of energy, and thus forms a new element neptunium; this is also β-radioactive and disintegrates to plutonium, which is reasonably stable, being an α-radioactive element with a half-life of 23 000 years. This can be expressed as:

$$^{238}U + n \rightarrow {}^{239}U \xrightarrow[23\,min]{\beta\text{-ray}} {}^{239}Np \xrightarrow[2{\cdot}3\,days]{\beta\text{-ray}} {}^{239}Pu \xrightarrow[23\,000\,years]{\alpha\text{-ray}} {}^{235}U$$

The affinity of the two isotopes for neutrons of different energies is shown in Fig. 1, where the affinity is expressed as equivalent to an area of cross-section of the nucleus for capture of the neutron whose energy is expressed in electron-volts. The fission capture cross-section for uranium 235 rises from about 1 barn* for the very fast neutrons released at fission to a value of 540 barns for neutrons having thermal velocities, that is with energies equal to 0·025 electron-volt. The capture cross-section for uranium 238 is given in two curves: for fission (see scale 2) it is less than 1 barn and is confined to the very high energy region, but for non-fission capture (see scale 1) there is an intermediate velocity of the neutron, neither high nor low, for which the affinity rises to 10 000 barns before falling to a low value for neutrons of thermal energy. There is another capture process of considerable importance in the economy of a reactor employing natural uranium. This is a process whereby uranium 235 is converted to uranium 236, which is not fissile, and at thermal velocities 20% of neutrons captured by the uranium 235 are lost by this process; only 80% produce fission. In fission of uranium 235, the average number of neutrons released is 2·45 per ^{235}U atom undergoing fission.

For an explosive fission reaction to occur, substantially pure uranium 235 is needed: for a controlled reaction to occur, ordinary uranium containing the two isotopes in normal proportions may be used if steps are taken to prevent the fast neutrons released at fission from encountering uranium nuclei until their speeds have been reduced to low values. At low thermal velocities the probability of a neutron producing fission of the scarce uranium 235 is approximately equal to the probability of its being captured by the 140 times more abundant uranium 238, and so if one of the neutrons released at fission causes further fission, thus perpetua-

* 1 barn = 10^{-24} cm².



1 *Neutron cross-sections of uranium*

Scale 1 —— ^{235}U fission cross-section.
--- ^{238}U absorption cross-section.

Scale 2 —— ^{238}U fission cross-section.

ting the chain reaction, the other neutrons might be absorbed by uranium 238, by uranium 235 to form uranium 236, or by impurity atoms; alternatively they might escape.

The reduction in velocity of fast neutrons emitted at fission occurs whenever neutrons are scattered by nuclei, and occurs fastest if scattered by light nuclei. The light elements, hydrogen, heavy hydrogen, beryllium, carbon and oxygen, have low affinities for neutrons and can therefore be used successfully to scatter neutrons and thus moderate their velocity. Fermi used carbon in the form of pure graphite as 'moderator' in the first 'reactor'. Fig. 2 shows a plan view of the Chicago reactor partly assembled; it contained 10 tons of uranium rods of 1 in. diameter (some as metal, some as oxide rods) forming a lattice of 8 in. pitch; these were inserted into 100 tons of pure graphite, so that most of the neutrons emitted at fission are obliged to traverse at least 7 in. of graphite, losing energy at each collision with a carbon atom; and they re-enter uranium metal at such low velocity that absorption by uranium 238 is just about equal to absorption by uranium 235, causing fission. To avoid excessive loss of neutrons by escape from the walls of the reactor, the ratio of its surface area to its volume must be below a limiting value: it is this consideration which sets the minimum, or *critical*, size of the Fermi reactor, and this principle of construction is basic to all the reactors built since 1942, with the exception of the so-called *fast fission* reactors to be described later.

Plutonium

The plutonium formed after the uranium 238 nucleus has captured a neutron behaves very similarly to the uranium 235 when bombarded by neutrons, undergoing fission for all velocities. As plutonium differs chemically from uranium, it can therefore be separated by chemical processes from uranium, whereas the fissile uranium 235 may be separated from the non-fissile uranium 238 only by very expensive physical processes. Reactors may thus be built primarily to convert the plentiful uranium 238 to plutonium, with the fission energy discarded, as were the three large reactors built during the war at Hanford, Washington. In these reactors the uranium rods clad in aluminium were water-cooled, and the water ran to waste. Smaller reactors built at Windscale, Cumberland, after the war were likewise solely plutonium producers, and were air-cooled, the air passing to waste. Alternatively reactors can be built primarily to enable the energy to be used economically, or they may be dual-purpose reactors.

High-Temperature Reactors

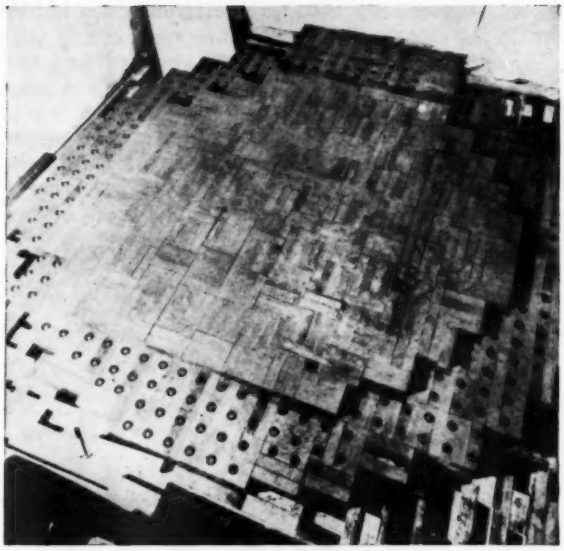
The first large high-temperature reactor was built for the United States submarine *Nautilus*, launched on the 21st January 1954: last year it completed its 20000 leagues under the sea without refuelling, ninety years after Jules Verne's imaginative story was written. Water is the moderator and coolant and is enclosed in a thick steel pressure vessel, so that steam is available from it at high temperature. As it is a relatively small reactor, the probability of neutron escape is not negligible, and in consequence the uranium must be enriched so that the ratio uranium-235/uranium-238 is much higher than 1/140; as uranium 235 costs about $10 per gramme the fuel cost is high but the performance of the submarine probably justifies this. To prevent the uranium from coming in contact with the water moderator, each piece of uranium is clad in a thin sheet of a zirconium alloy, a metal not corroded by high-temperature pure water, and not having a high absorption affinity for neutrons.

The second high-temperature reactor to be put into operation (June 1954) was a 30 MW (heat) land-based power station in Russia. The moderator is graphite and

the uranium is water-cooled, but to avoid a large high-pressure vessel, hollow rods of uranium are encased separately in thin stainless-steel tubing through which high-pressure water at 1 500 lb/in.^{2} is pumped and raised to 480° F—without boiling—by the energy of fission. Fig. 3 shows a view of the top of the reactor from which the 128 fuel channels emerge; the separate cooling of each element makes for a complicated design but reduces the water in the reactor to a minimum. This is an important consideration because water has an appreciable affinity for neutrons, and so its use represents a loss of neutrons available for the fission process; in addition the sudden removal of water would result in a *rise* of the neutron population, and an increase of reactivity which might be of dangerous magnitude. The core of the reactor is small, a cylinder 5 ft in diameter and 6 ft high enclosed in a graphite reflector; so neutron loss is high both from escape, and from absorption in the coolant and stainless-steel tubes encasing the fuel elements: the fuel must be enriched by from 0·7% to 5% of uranium 235—with two consequences, a high cost of power generation and a low yield of plutonium, only three atoms of plutonium being produced for every ten atoms of uranium 235 undergoing fission.

The third successful high-temperature reactor to operate is the dual-purpose reactor at Calder Hall. The moderator is graphite, and cooling is done by carbon dioxide gas at high pressure contained in a steel pressure vessel of 2 in. wall thickness. This reactor is so large and constructional materials absorb so few neutrons that the proportion of neutrons lost is very low; in consequence natural and not enriched uranium can be used. The gas flowing over the uranium rods encased in finned magnesium-alloy tubes is passed through four heat exchangers, where steam is raised and used to drive two 23 MW turbines. Of the 2·45 neutrons released at fission, 0·8 convert uranium 238 to plutonium, one maintains the chain reaction, 0·3 are captured by uranium 235 converting this to the useless uranium 236, and the balance are captured by carbon and impurities or they escape from the reactor.

In Great Britain, owing to our coal shortage and our continued rapid increase in the demand for electricity—an approximate doubling in each of the past four decades—the gas-cooled power reactor is being built on a large scale. Three more stations of the size of Calder Hall—where there are now two reactors delivering 92 MW of electricity—are being built after the pattern of the first; four larger stations operating at higher pressures but of the same basic design are being built by industry and are due to produce 1 400 MW by 1961, and by 1965 a total of 6 000 MW is expected to be generated from nuclear power. This represents one-third of the new electrical generating plant which will be provided by 1966, so that coal to the extent of about

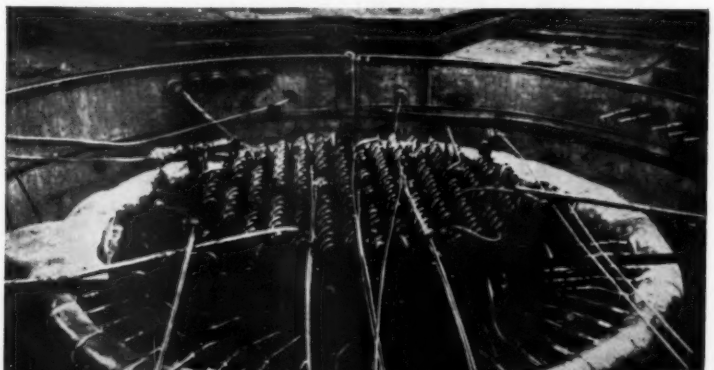


2 *Plan view of the first reactor in the course of erection at Chicago*

This reactor, which had the first self-sustaining system, was initially operated on the 2nd December 1942.

15–20 million tons per annum will be saved by that date. Within a further decade it is likely that all new generating plants will be nuclear so that our need for converting the energy in coal to electrical energy is likely to decline very greatly in the last quarter of the century, but this time is clearly too far ahead for anything but the most cautious opinion. Bearing in mind our country's very limited reserves of coal in relatively easily worked seams, and the need to conserve coal for converting to oil and other chemical substances, and for making steel, we appreciate that the advent of nuclear

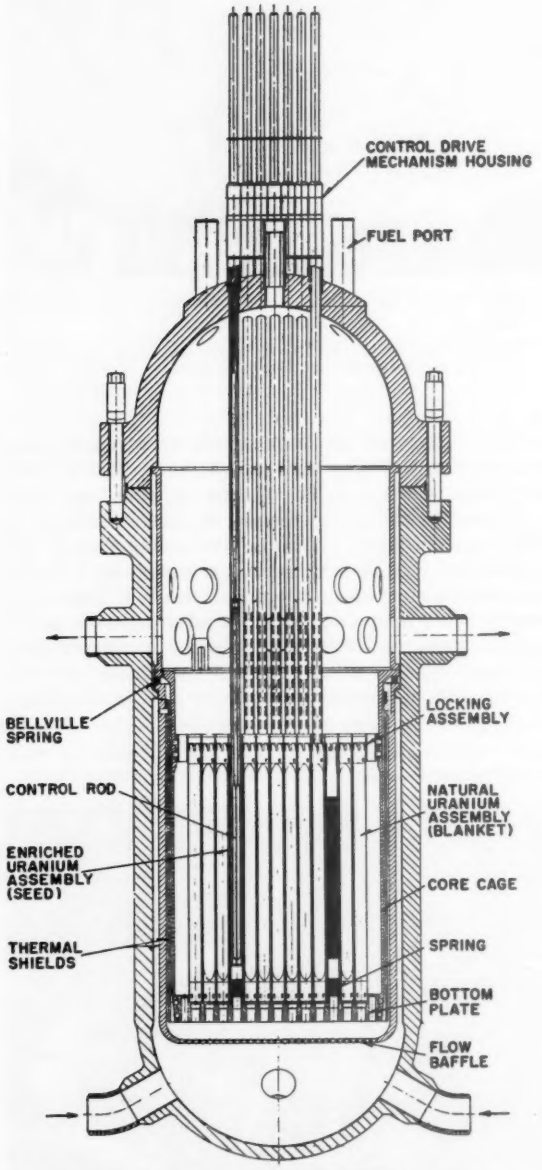
3 *Upper part of the Russian 30 MW reactor with the iron covering plate removed, exposing the water-cooling system for the fuel elements*



power has come at a most fortunate moment in history for the inhabitants of Great Britain.

Other Types of Reactor

There are very many alternative forms of reactor now being developed oversea. The largest in America is the pressurized water reactor at Shippingport, which began to operate in 1957 and is designed to produce 60 MW of electric power; it functions on the same principles as the reactor in the *Nautilus* and there are very many submarines and other naval vessels being constructed with reactors of this type, all of which use enriched fuel. It is shown in outline in Fig. 4; it comprises a 250-ton steel vessel of internal diameter 9 ft, and of height 33 ft, having a wall thickness of 8½ in. to withstand an operating internal pressure of 2000 lb/in.² and made in two sections bolted together. The core is a cylinder 6 ft in diameter and 6 ft high which contains a number of sub-assemblies of highly enriched uranium 235, surrounding and surrounded by more sub-assemblies of natural uranium in the form of oxide. This core is shown in cut-away form in Fig. 5; each sub-assembly of enriched uranium consists of many thin plates of uranium-zirconium alloy sandwiched between zirconium-alloy plates, welded to prevent contact between water and uranium. The uranium-zirconium alloy is used in preference to uranium metal since it does not undergo the dimensional changes which uranium exhibits under irradiation, and the sandwich cladding is not corroded by water at 550° F. These sub-assemblies can be removed singly when the reactor is not in operation, but no provision is made for removal whilst on load. As 60% of the power is generated in the natural uranium sub-assemblies and 40% in the enriched, there is, unlike the Russian reactor, a large conversion of uranium 238 to plutonium: eight atoms of plutonium are formed for every ten atoms of uranium 235 disintegrating, and so the lifetime of fuel elements in the reactor is expected to be long. Water enters the vessel at the ports at the bottom, flows past the core at 20 ft/min, and then passes to heat exchangers, where heat energy is given up to raise the secondary water to 500° F.



4 *Longitudinal section of the 240 MW high-pressure water-cooled water-moderated reactor at Shippingport, United States*

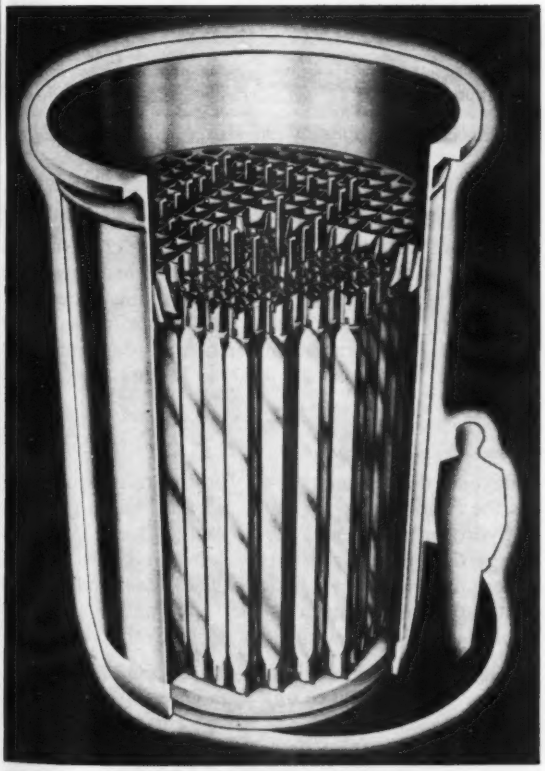
A variant of this design is to allow the water to boil under a moderate pressure whilst flowing over the fuel plates. After many experiments in France at the Argonne laboratory, where an experimental core has been allowed to destroy itself, a 20 MW (heat) reactor has been constructed, and recently generated 5 MW of electricity. Owing to the small size, the core plates contain highly enriched uranium, but it is expected that, with a large reactor, natural uranium would be used. Because the pressure is limited to 300 lb/in.², steam voids are formed as the water rises between the fuel element plates, and these reduce the reactivity of the core, thus making for power stability.

Another reactor constructed in the United States employs liquid sodium metal as coolant flowing over uranium rods encased in thin zirconium and over blocks of graphite moderator likewise encased in zirconium: a fairly expensive construction justified, possibly, by the avoidance of high pressures and the attainment of high operating temperatures, but one which also needs enriched fuel. The relative merits of these liquid or liquid metal-cooled reactors cannot be accurately judged yet, and as all of them need enriched uranium fuel, the cost of electricity generated from them is likely to be high until they operate at very large powers.

Fuels, Moderators and Coolants

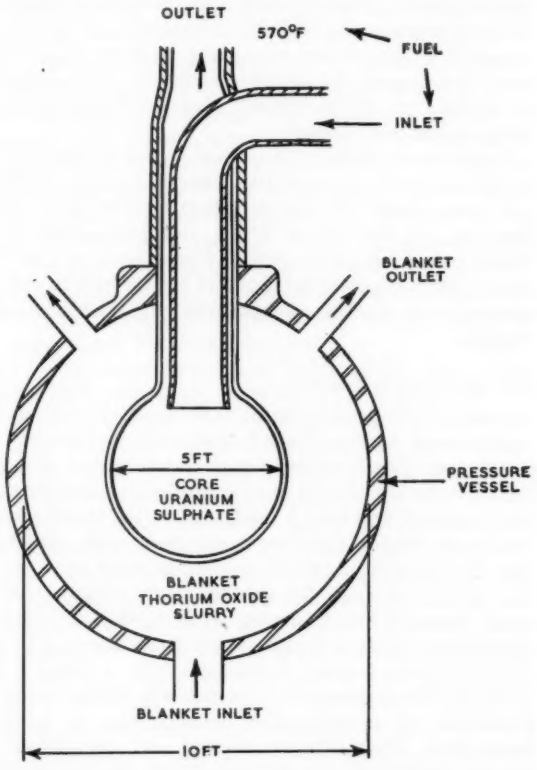
The elements into which uranium breaks up, the so-called fission products, absorb neutrons in varying degrees, and there is a limit to which their concentration can be allowed to build up without impairing the performance of a reactor. The metal must therefore be removed from the reactor, so that it can be dissolved in acid and the fission products removed, after which the uranium can be used again with a suitable replenishment of fissile atoms. This is an expensive procedure, and several experimental reactors have been designed to operate without the necessity for fabricating rods of uranium. In one design illustrated in Fig. 6, uranium sulphate dissolved in heavy water is contained within a spherical zirconium-alloy vessel surrounded by a thorium-oxide slurry suspended in heavy water. Neutrons escaping from the core will be captured by the thorium, which undergoes transmutation to form a uranium nucleus (uranium 233), which, like uranium 235 and plutonium 239, is fissile by neutrons of all velocities; and it is expected that more atoms of thorium will be converted into fissile uranium 233 in the blanket than the number of atoms undergoing fission in the core.*

5 *Cut-away view of core of Shippingport reactor*
The uranium fuel elements are encased in zirconium alloy.



* Uranium 233 has an affinity similar to uranium 235 for neutrons of thermal velocity but almost all these neutrons cause fission; very few are absorbed parasitically to form the useless uranium 234.

Such a reactor is referred to as having a *breeding coefficient* greater than unity. Continuous circulation of the fuel and blanket solutions through heat exchangers removes the energy, and continuous chemical extraction of the fission products avoids wastage of neutrons by parasitic capture. Two of these liquid-fuel reactors have operated at low power and appear to hold considerable



6 *Design of a large American liquid-fuel reactor employing a core of uranium sulphate dissolved in heavy water and a thorium-oxide slurry blanket*

promise for the future. Of special value is the high inherent nuclear stability due to the large negative temperature coefficient of reactivity; and the explosion hazard arising from the generation of hydrogen and oxygen in the liquid of core and blanket is removed by catalytic recombination of the gases as they rise with the steam from the reactor.

Experiments are being conducted on the use of organic liquids of the diphenyl type to replace water as a coolant. These boil at temperatures of 300–400° C and could be used as coolants and moderators at far lower pressures than are necessary for water-cooled reactors. Other experiments are being conducted on uranium and thorium dissolved in liquid metallic bismuth, with the ultimate aim of constructing a graphite-moderated reactor (see Fig. 7) having a core of liquid bismuth

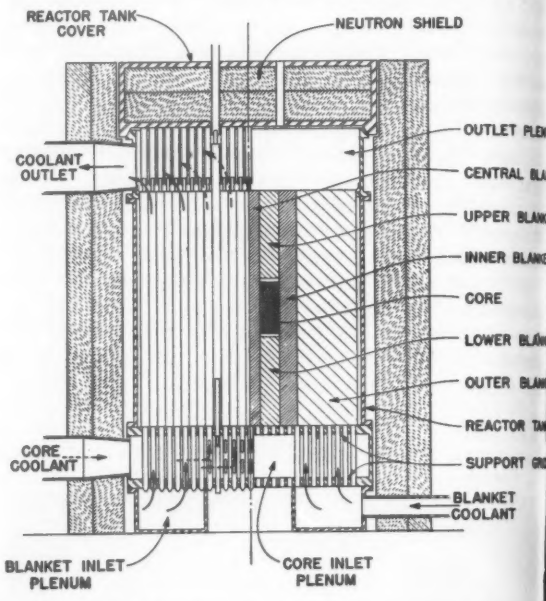
carrying one per cent of uranium 233 or 235 in solution up channels in the graphite, and a blanket of bismuth carrying a thorium compound in solution. The inlet temperature of the bismuth would be 400° C; that of the outlet would be well over 500° C, and heat would be extracted from this via a sodium interchanger to raise steam. High-pressure vessels are thus avoided for the reactor, and at these temperatures there is no reaction between graphite and bismuth. Neutron losses are small enough for the reactor to appear to have a breeding coefficient greater than unity, and fuel processing would be continuous, if the present ideas of fission product extraction prove successful.

It must be emphasized that there are a large number of possible combinations of fuel, moderator and coolant, and many years will elapse before existing ideas have been put to the test of design and production. It is indeed astonishing that, within fifteen years of the first reactor being constructed, reactors can be built to deliver electricity at a price competitive with the coal-fired station.

The Fast-Fission Reactor

Finally, it is possible to dispense with the moderator and to create fission with fast neutrons if highly enriched fuel is used. The total amount of uranium thus required for a given rate of release of energy is far smaller than when natural uranium is used, and so the specific heat-loading of the fuel elements is extremely high, necessitating the use of liquid-metal cooling in place of water or gas cooling. Because the volume of the reactor core is small, neutron loss by escape is high, but this can be turned to advantage by surrounding the core—as in the fluid reactors already mentioned—by a blanket of uranium 238 or thorium 232 which will be converted to plutonium or uranium 233, respectively, by neutron absorption. A fast-fission reactor, e.g. as shown in section in Fig. 8, has no moderator but an efficient blanket. Such reactors are *breeder reactors*, with breeding coefficients well in excess of unity. They may therefore be destined to play an essential role in any country's nuclear energy programme, since, by their use, it becomes possible to burn up all the uranium 238 instead of an amount two to four times the amount of uranium 235 burnt up in a natural uranium reactor of the Calder Hall type. The 60 MW reactor at Dounreay, due to operate this year, has a core of highly enriched uranium rods encased in niobium tubes, which are cooled by liquid sodium or sodium-potassium alloy, and it has a blanket of uranium 238 rods encased in stainless-steel tubes. The primary coolant, which will become radioactive through neutron absorption by the sodium, delivers its heat to a secondary liquid-sodium coolant system, which will remain non-radioactive; in turn this will deliver its heat to water for conversion to steam. The whole of the reactor and primary coolant system is built within a 135 ft steel sphere, so that, in the event of accident and release of fission products, all will be kept within the sphere.

It should be mentioned that the first high-temperature reactor ever to operate was the American experimental breeder reactor which was completed in 1951. It has yielded an enormous amount of valuable data, but the Dounreay reactor is much larger, and if successful will be a prototype for many advanced industrial designs. The great scientific attraction of the fast-fission reactor



7 *Schematic elevation of American experimental breeder reactor*

is that fast neutrons are not lost by parasitic capture, or capture in fission products and in constructional materials, to the same extent as are slow neutrons. Thus, if loss by escape can be prevented, breeding ratios ought to be high, particularly when plutonium is used in the core, since the average number of neutrons emitted for fission is 2·9, compared with 2·45 for uranium 235 and uranium 233.

Thermo-Nuclear Reactions

Beyond the fission process for the release of energy lies the fusion process, the creation of helium nuclei out of hydrogen nuclei and the consequent release of more energy than is released by the same weight of uranium undergoing complete fission. The reactions between deuterium and tritium nuclei are well known (see Table 1), but as these nuclei are positively charged they

Table 1. Reactions between Deuterium and Tritium Ions endowed with High Energy

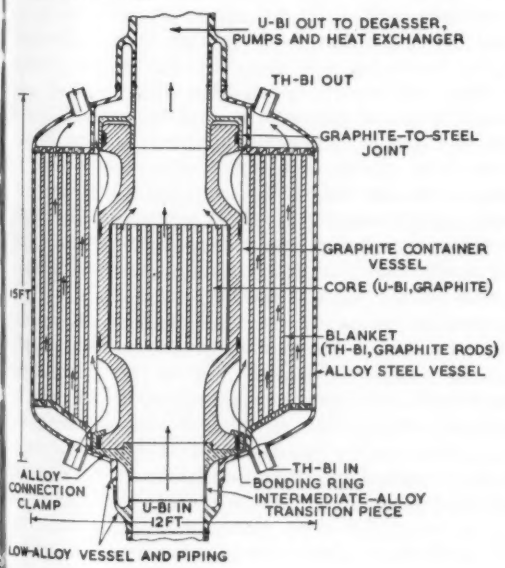
D + D	→	p + ^{3}H	+	4·03 MeV
D + D	→	n + ^{3}He	+	3·25 MeV
T + D	→	n + ^{4}He	+	17·6 MeV
D + ^{3}He	→	p + ^{4}He	+	18·34 MeV
T + T	→	2n + ^{4}He	+	11·3 MeV

have to be raised to high energy to overcome the force of repulsion between them. In the hydrogen bomb, this high energy is acquired from the explosion of a fission bomb within a blanket of deuterium and lithium; in a controlled thermo-nuclear reaction it must be acquired by electrical means, and the nuclei must acquire energies of 10–100 keV (corresponding to 'temperatures' of 100×10^6 degrees); but as the released energy per nucleus is in the region of several mega-electron-volts, the margin for a net gain of energy from the reaction appears at first sight to be reasonably large. Such temperatures can be reached in electrical discharges carrying currents of the order of 10^5–10^6 amp, and fortunately at such current magnitudes, the accompanying magnetic field exerts such a large pinch-effect* force on the current carriers, electrons and deuterium ions, that the high-temperature gas plasma is confined to a narrow core.†

From this core, neutrons have been produced by several investigators, but at the time I gave the Faraday Lecture these neutrons had not arisen from an equilibrium state with substantially all the plasma at a high temperature, but rather from a transient state in which, owing to high rate of change of inductance of the plasma, high local gradients had been set up which were capable of accelerating the ions to speeds great enough for fusion to occur locally.

* During the lecture an animated film showed the operation of the pinch-effect forces on the ionized gas plasma as the current rose to 10^6 amp, so constricting the discharge into a small-diameter concentric channel, well removed from the walls of the vessel. At the peak of the current wave, fusion of the deuterium ions takes place, radiant heat is absorbed by a water shield, and neutrons are absorbed by a uranium 238 blanket to produce plutonium.
† The magnetic field also affects the deuterium ions, but to a far smaller extent because of their lower velocity; they are, however, pulled into the narrow core of electrons by electrostatic attraction.

8 *Graphite-moderated reactor with liquid uranium-bismuth solution in the core and liquid bismuth containing thorium in the blanket.*



Since then stable discharges have been produced at the A.E.R.E. in an apparatus known as Zeta, and at the A.E.I. Research Laboratories, in an apparatus known as Sceptre. Both these are metal torus-shaped vessels in which an electrodeless discharge in deuterium gas is created within the torus by an electromotive force induced around it. As the discharge contracts under the influence of the pinch-effect force, instabilities arise owing to the self-magnetic field and these cause the discharge to move rapidly towards the walls of the torus. In doing so, eddy currents flow in the metal walls which tend to repel the approaching discharge, and almost complete stability can be achieved by imposing a steady magnetic field parallel to the axis of the gas current. As the discharge constricts itself in the presence of this axial field, currents circulate around the axis of the discharge channel, thus augmenting the axial magnetic field within the channel and reducing it outside the channel; in effect the discharge *traps* the axial magnetic field on contracting. Articles describing these results have recently appeared in *Nature** and *The New Scientist*†.

In both experiments gas temperatures have been measured by observing the width of a spectrum line of an impurity element (the deuterium atom is stripped of its electron at these temperatures and can therefore emit no light, but an oxygen atom is only partially stripped—say four electrons are stripped from it—and it can therefore still emit light in the form of a line spectrum). Normally the width of a spectrum line is extremely narrow but if some ions are moving away from the spectrograph and others are moving towards it, the wavelengths of the light received by the spectrograph will differ from the normal and the line will be recorded wider than is usual—the so-called Doppler broadening of the line. Thus, the width of the line gives a direct measure of the velocity of the ions in the gas and hence of their temperature; temperatures of 4–5×10^6 degrees have been observed over times lasting from 500 to 2000 microsec. Neutrons have been emitted over the whole of these times; 10^6 neutrons per discharge pulse emitted from Zeta, and 10^5 neutrons per pulse emitted from Sceptre. There is, therefore, much greater reason to believe that these neutrons are of true thermo-nuclear origin; of course, they arise—and can only arise—from collisions between deuterium ions, but the number observed is very approximately that which should arise from a plasma at this mean temperature.

Fortunately the neutron emission rises very rapidly as the temperature rises, according to a tenth-power law. At present about 10^{-12} of the energy put into the torus appears as neutron energy, but an increase of temperature of only 100 times—probably resulting from an energy input to the discharge ten thousand times higher—might produce an increase of neutron energy of 10^{20} times, in which event the output would greatly exceed the input. It is possible only to guess how fast progress will be. I said in the lecture itself (for the first time in November 1956) that '. . . rapid progress can be expected,

* 25th January 1958. † 30th January 1958.

and I believe that within a five-year period thermo-nuclear reactions will be well established, and within a ten-year period, a reactor producing some power—not necessarily more than the input power required—will be in operation. As deuterium occurs in the ocean to the extent of 1 atom of deuterium for every 5000 atoms of hydrogen, the supply of thermo-nuclear energy will be inexhaustible if ways are found to release it efficiently.'

The Fission Products and Irradiation

Each ton of uranium produces a ton of highly radio-active fission products, and so by 1965 reactors in Great Britain will be producing a few tons of fission products per annum; although the radioactivity of some of the elements decays in a short time several of the elements are radioactive for long enough to be used industrially. A list of the important long-lived fission products is given in Table 2.

Table 2. Long-Lived Fission Products

Radioactive elements	Half-life
Caesium (β, γ)	30 years
Strontium (β)	28 years
Cerium (β, γ)	285 days
Zirconium (β, γ)	65 days
Xenon (β, γ)	5·27 days

Many possible applications for large intensities of radiation, mainly γ-radiation, are being explored. Caesium emitting a 660 kV γ-ray with a half-life of 33 years has been concentrated to yield a specific activity of 50 curies/cm^3, and as such can be used in place of radium in massive concentrations for deep γ-ray therapy. The first two of such 1000-curie sources have been installed in the Royal South Hants Hospital, Southampton, mounted on the opposite ends of a diameter of a ring 1 m apart, so that a typical focal skin distance from source to patient is 40 cm, and the dose rate is 30–60 röntgens/min at the skin. These sources occupy larger volumes than the cobalt 60 sources which can be obtained by irradiation of cobalt metal in a reactor, but the latter involve the expenditure of neutrons to produce them; caesium is one of the most abundant of fission products and its cost should ultimately be only the cost of chemical concentration. An important advantage of the caesium over the cobalt source is that the latter has a half-life of only five years and thus needs frequent recalibration, and not infrequent replenishment.

Caesium γ-ray sources are also being used for weld examination, but for sharp definition the size of the source must be small, and here caesium is not so attractive as the pile-made γ-ray emitters such as cobalt. For medical diagnostic use, Professor Mayneord has developed a small xenon source which uses the fission product xenon 133 absorbed in a small pellet of charcoal 1 mm in diameter; this is mounted on a flexible cable so that it can be retracted into a lead holder when not in use. An exposure of 15 sec with a 10-curie source suffices for radiography of a hand, for example, and the obvious application of such small portable sources is for field use and for radiography of the body from places inaccessible to X-ray machines.

Massive γ-ray doses are being considered for food sterilization. Doses of only 20000 röntgens kill the life-cell in root crops like onions and potatoes without destroying nutritional values. So far, meats and milk and bread sterilized with γ-rays of 10^5–10^6 röntgens have slightly distasteful flavours or odours, but it has not been established that these disadvantages must necessarily accompany sterilization, and work on this is still being actively pursued. It is known that γ-irradiation considerably prolongs shelf life of refrigerated foods and this without the disadvantages mentioned above. If fission sources of γ-rays are found to be possible for food preservation, it is calculated that the world's fission stocks will ultimately be so large that they will suffice to treat all the world's food.

Irradiation of pharmaceutical products, particularly those destroyed by heat, appears very attractive; irradiation to sterilize hospital equipment such as blankets, sutures, dressings, etc., to sterilize human arteries, bones, etc., to await transplanting operations, has been achieved on a modest scale. Irradiation has been given to sterilize male flies in colonies of both screw-worm and tsetse fly so that the eggs of the next generation of flies are sterile: this extremely important discovery and practice eliminated the screw-worm fly from Curaçao in one season. The low dose of radiation (50000 röntgens) required for insect eradication in grain products results in a comparatively low cost of preservation.

Irradiation of complex molecules has achieved great success in a few examples, such as the cross-linking of polythene molecules—resulting in the raising of the softening point by 50–80° C; some polymers can be made from ethylene in the presence of γ-rays at lower temperatures and pressures than are necessary for normal polymerization: rubbers have been vulcanized, and chlorinated benzene and other similar compounds have been made with γ-radiation without heat and without the use of catalysts. In making artificial blood serums, γ-rays effect a serum of unique molecular weight, whereas heat creates a complex series of serums of different molecular weight. These are but a brief mention of some early successes; a whole new chemistry might arise from γ-irradiation, the economics of which is tied to the power-reactor programme and the cost of chemical separation of the fission products.

In Brookhaven and in Norway 5000-curie sources of γ-rays have been used by plant geneticists to study the effects of γ-rays on growth and on gene mutation. Growth does not seem to be stimulated beneficially by irradiation, rather the opposite: no plants near the source are as healthy as normal plants, but of the many varieties produced by irradiation some appear to be of great value. Again this huge subject is in its infancy, and so a few examples must suffice to indicate what the future might hold in store. A barley has been 'discovered'

(there is no other word for it; the biophysics is too difficult to enable a forecast to be made of the effects of γ-rays on life cells) with a stronger stem capable of withstanding winds better; another variety maturing earlier has enabled barley to be grown further north than heretofore. Oats immune to rust disease, tobacco immune to virus, wheat with a shorter straw, and a peanut with a 30% higher yield: these are but the first fruits of a new applied science.

Radioactive Isotopes

Almost all elements absorb neutrons and in so doing form unstable nuclei which subsequently disintegrate with the emission of positive or negative electrons, γ-rays, or both. Detectors are now sensitive enough to reveal single disintegrations, and so we have a method of extreme sensitivity for following chemical or physical processes in which traces of radioactive isotopes are deliberately introduced. So widespread has this new technique advanced that Great Britain and the United States have produced over 100000 samples of radioactive elements, either in elemental form or in compounds for use in every branch of science in all countries of the world, and an encyclopaedia would not suffice to recount the discoveries made through following processes more exactly than ever before with the aid of tracer elements. I can but take an example here and there from different sciences by way of illustration.

In the preparation of some of the semi-conducting elements, such as silicon and germanium, it is important to know the nature and concentrations of residual impurities in crystals of these elements as they are grown from the melt. Some impurities such as indium are found to be more soluble in liquid than in solid germanium and so tend to be left behind as the germanium crystal grows in length. If radioactive indium is introduced into the melt it can be shown that the amount of indium captured in the germanium crystal lattice is less than one part in 10^8. Alternatively, an element such as silicon may be irradiated in a reactor, and impurities such as phosphorus and arsenic will be made radioactive by neutron bombardment. They can then be separated from the silicon by chemical methods, and concentrations as low as 10^{-9} or even 10^{-10} in the silicon can be detected.

In a polycrystalline body diffusion has been shown to occur preferentially along grain boundaries, and by using radioactive tracer elements it is even possible to measure the self-diffusion of an element. Fig. 9 shows the penetration of radioactive tin into tin and into nickel. This photograph was produced by *autoradiography*, wherein a photosensitive surface is placed in contact with a sectioned sample of the metal and is activated by the β-radiation from atoms of tin which have diffused into the body. The method is extremely valuable in producing quantitative data on diffusion, and in gaining an insight into the effect of minor amounts of impurities upon the properties of metals.

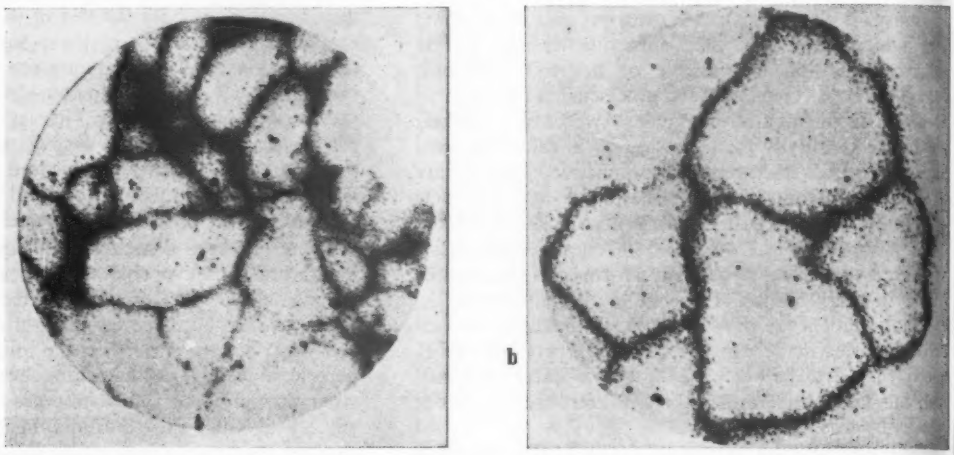
It is important in river estuaries and harbours to understand fairly exactly the movement of the tides and their influence on dredging and silt. Dredging in the Thames is necessary to remove the silt brought down by the river and deposited in the region of the docks. The extent to which silt carried farther down the river was brought up the river by undercurrents was not known, but it was known that far more silt has to be dredged than is brought down by the river. Quantities of silt mixed with the radioactive tracer element scandium 46 (half-life = 85 days) were released below Tilbury docks as the ebb tide was flowing, and at a later time samples were brought up from the bed of the Thames. From the measured radioactivity of these samples it was shown that silt is carried downstream for a distance of a few miles, but that also a quite considerable quantity of silt was carried farther up the Thames; in fact, radioactive silt was detected 15 miles farther up the river than the point at which it has been released. It is difficult to see how this kind of information could have been gleaned without the use of radioactive tracer elements.

There has been a multitude of industrial applications of tracers to the problems of location. For example: finding leaks in water pipes; detecting leaks in petrol tanks of aircraft; tracing underground water courses; studying the points of entry of water forced into petroleum wells; distinguishing between turbulent and streamline flow of fluids in pipes; and measuring the efficacy of mixing in solutions, in liquid metals, and in gaseous reactions. Here are some examples in the iron and steel industry. If pellets of radioactive materials are placed in the lining of a blast furnace as it is constructed, their disappearance can be noted as the lining is slowly eroded away, and the lining can be renewed before the furnace breaks open. When steel is poured from a ladle it will be found to contain some non-metallic inclusions too small for analysis, but with tracer elements it can be shown that these have come from the tip of the ladle. In steel making, the degree of mixing of ferro-alloys into liquid metal can be followed with high precision.

The study of metallic wear has been greatly helped by the use of tracer elements. To measure the rate of wear of a metal piston ring one can first irradiate the ring in a reactor, place it in an engine, and circulate the lubricating oil, which contains the worn fragments, in front of a detector. In this way the rate of running-in as a function of load, speed, wall temperature and nature of lubricant has been accurately determined, resulting in a marked reduction of the running-in time. The extreme sensitivity of the method may be illustrated simply by drawing a radioactive indium electrode once very lightly over a sheet of aluminium: a detector will instantly show the path followed by the indium; or a very small spark may be passed between a radioactive cobalt electrode and copper: the amount of metal transferred in the spark will be less than 10^{-12} g but may be detected.

In agriculture, tracers have been used extensively to measure the efficacy of fertilizers at various times in the life of a plant. It is remarkable that within 15–20 min of a rootlet contacting a grain of phosphorous fertilizer,

the phosphorus travels up to the leaves—as can easily be shown in an experiment with phosphorus 32—and thus the rate of assimilation of fertilizer can be determined by direct observation. Immediate economic benefit can be gained by placing fertilizer granules a few inches below newly sown seed instead of scattering it generally over land, where much of it will be displaced sideways from the growing rootlets by several inches. The most appropriate time for adding fertilizer has been determined for different crops. When fruit is setting, some plants are



9 *Diffusion of radioactive tin in* (**a**) *tin and* (**b**) *nickel*

The magnification is 30.

incapable of absorbing phosphorus through the roots but can absorb fertilizer through the leaves, and a new science of non-root nutrition is growing up. Apart from experiments having a direct industrial application of this kind, tracer experiments have already yielded an enormous fund of basic biological knowledge which could hardly have been gained by classic methods. It was not realized until tracers were used that the products of photosynthesis reach the growing points of plants within a few minutes, that sap can rise in trees in dry weather at a rate of 3 ft/min, and that tree roots so graft onto one another that a forest must be regarded as a community rather than a collection of separated trees so far as the movement of sap is concerned.

Finally, tracers have become of extreme importance in physiology and medicine, not only in providing exact knowledge of movement and location, but also in fundamental studies of metabolism. Sodium 22, chlorine 38, indium 131 and potassium 42 have been used to measure blood flow, efficiency of cardiac mixing, absorption and transfer. The advantage of remote measurement is especially important when dealing with life: the selective absorption of iodine in the thyroid gland enables a plot to be taken with a scintillation counter traversed over the gland 10–15 min after ingestion of an iodine solution, thus delineating it. In this way, after an operation for removal of the gland, it is possible to detect whether any thyroid tissue remains in the neck. Some brain tumours can be located by their absorption of radioactive iodine in the form of di-iodofluorescein.

In applying isotopes to the study of metabolism much has been learned, but an even more complex pattern of life has been revealed, over which controversy will reign for many years. Without tracer elements in compounds of many varieties these facts would probably never have come to light; they could have been inferred probably after much experimenting, but with tracers the kinetics of biological reactions can be accurately determined.

Thus, as nuclear energy has come in the nick of time to supply the world with heat energy in the twenty-first century and for a million years thereafter, so the by-products, the fission products, may find a vast industrial application almost inconceivable in magnitude to-day. The radioactive tracer elements will be available for ever to make science more exact, to improve our knowledge of medicine and agriculture, and so help us in the problem of feeding a world whose population doubles in a century.

It gives me the greatest pleasure to record here my thanks to my chief assistant, Mr. E. F. Chivers, who made many of the models for the original lecture and with me most carefully studied the presentation of it and of the experiments; and to my other assistants, Mr. D Allenden, Mr. N. B. Warren and Mr. D. E. Purse.

CHECK YOUR SPEECH POWER

A revealing formula for success in public speaking was given at the Symposium on Engineering Writing and Speech, held in October last year by the Professional Group of the Institute of Radio Engineers. The formula is:

$$P_p = (K_f + K_s)^{cde} + P + R_e$$

where P_p = platform poise, K_f = knowledge of the fundamentals of a good speech, K_s = knowledge of the subject, c = confidence in yourself, d = desire to communicate information, e = enthusiasm, P = practice, and R_e = repeated experience.

No units or typical values for an American (or Englishman) were provided. Nevertheless, it may be encouraging to engineers who have little opportunity of public speaking, but some faith in mathematics, to know that a combination of knowledge, confidence, desire and enthusiasm makes a far more potent contribution towards effective speech-making than do practice and experience.

SHORT REVIEWS OF PAPERS

On the following pages are some brief review articles based on, and written by the authors of, current Institution papers. The authors have been asked to make these articles, so far as possible, interesting and of appeal to electrical engineers who have no specialized knowledge of the subjects, and the content of the articles is not necessarily confined to the subject-matter of the original papers.

Stage and Television Lighting

A short review of a Utilization Section paper (No. 2424) entitled 'Electric Control of Stage and Television Lighting' by F. P. Bentham. The paper was published individually in November 1957 and it will be republished in Part A of the Proceedings. The author is with the Strand Electric and Engineering Co.

THE CONTROL OF STAGE LIGHTING, AND TO SOME EXTENT of television lighting also, presents a problem quite different from that of a simple collection of a large number of controls on a switchboard. The stage control has to weld a large number of circuits together so that the whole stage-lighting installation becomes an instrument of artistic expression—such a control being operated by an artist, possibly, instead of an electrician. In the author's opinion, this control has a closer affinity with the switchboard successfully concealed beneath every modern organ console than with an orthodox electrical control panel.

Fig. 1 shows what is known as a *box set*, in which the various naturalistic lighting effects peculiar to anything from high tragedy to farcical comedy may be staged. At the moment of the photograph one of the room lights has just been lit. This *cue* has been preceded by a late afternoon merging slowly into a sunset and then into dark night outside the window, and by fire-light within the room. The room lights are switched on by the actors in two cues—one for the candelabrum on the fireplace and one for the table lamp. Later on, these lights will be taken off for a scene in the moonlight, which by then will be shining through the window, and the scene will close with a slow fade-out.

1 *Typical interior stage set*

The lighting plot could be much more complicated in a spectacular show. To produce it originally and to repeat it at each performance may require quite extensive electrical control facilities.

The first point is that none of the apparent sources of light provides the real lighting of actors and scene. They only appear to do so. The actual lighting is built up of a mosaic of localized beams from spotlights and accessory lanterns in many positions and at many angles on the stage and in the auditorium. Each successive picture (*lighting effect*) has to be 'painted' with light by means of these sources.

Each single source or group of sources, which has some character of its own to contribute, forms a separate circuit back to the switchboard, where a control channel, or *way*, is provided for it. The principal feature of a control channel is its *dimmer*, which allows regulation of light intensity down to zero (*blackout*) by reducing the line voltage. Tungsten lamps are still the backbone of both stage and television lighting.

For theatres, installations usually fall into three ranges: small installations with 36–72 dimmers, medium-sized installations with 100–152 dimmers, and large installations with 180–300 dimmers. To keep the size of the control panel as small as possible, remote control of the load-carrying apparatus is usual, and dimmers for this purpose fall into two groups—the all-electric and the servo-operated (or electro-mechanical). The all-electric group includes the saturable reactor and the electronic dimmers, all of which need an activating current to retain them at any level other than blackout. The servo-operated group comprises resistors and/or auto-transformers, whose tapping arms are driven by electromagnetic clutches and/or motors through servo connections to the control levers. The electro-mechanical arrangement has the advantage of inertia, which enables the dimmer to be set at any intensity level and ensures that it will retain that level when the control lever is disconnected. This has led to a technique where the operator sets only the controls of those dimmers which have to change intensity.

At rehearsal, the producer or his lighting director will call for the various circuits and their dimmers to be set visually to paint the particular picture. Dimmers are used to balance the light (i.e. to cause some sources to dominate others), or to provide the general level of intensity, or to cause a particular admixture of one colour of light with another. When at last the picture appears correct, it is plotted, and the operator passes on to the next set of levels for the next picture. The change from one set of levels to another may be not only of dramatic importance but also part of the play

2 *Organ-console type of lighting control in operation at the Palace Theatre, London*
The console controls 120 dimmers.

proper, as in a slow sunset or the sudden switching on of the lamp fittings supposed to be lighting the scene.

Each of these lighting changes involves a different unrelated group of circuits, and a stage-lighting control must make provision for grouping, so that such changes may be actuated by one control or by the number of controls which it is possible for one man to operate simultaneously. If organ-console techniques are adopted, use of the fingers and feet can make this number twelve. A 120-dimmer development of an organ console in use in the wings at the Palace Theatre, London, is shown in Fig. 2.

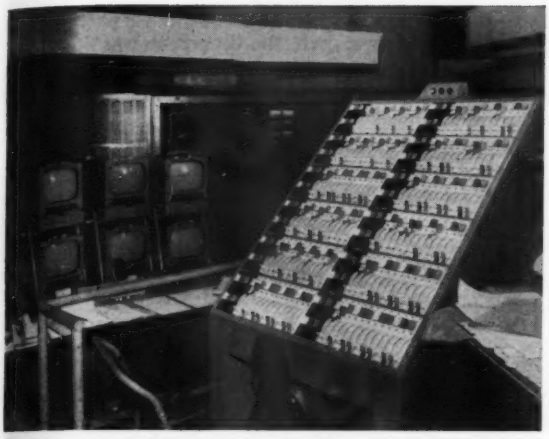
The author's work has always featured the 'playable' approach to the control, but others have preferred to make provision for setting up a series of complex changes in advance and invoking these by means of a cross-fader. This has led to the multi-preset control, in which each dimmer lever is repeated ten times, and an example of this for 80 dimmers is shown in Fig. 3. Of course, ten

3 *Multi-preset control in a colour-television studio in New York*
80 dimmers are controlled.

presets will not cover all the lighting pictures in a production—sixty or more being common—but as the changes tend to bunch together, use is made of a convenient lull to reset the levers. The multiplicity of levers required by the multi-preset system leads to difficulties of accommodation when 100 or more dimmers are required.

There are at present eighteen television studios in this country with centralized remote control of their production lighting. All have been installed in the last two-and-a-half years.

For television, the control has to switch on those lighting circuits required for the area of the studio in camera view at any given moment, because it is advisable at times to keep to a minimum the lighting in other areas of the studio to reduce demand on mains and ventilation plant. Dimmers are required primarily to balance lighting intensity and to a lesser extent for theatre-type changes within a scene. Grouping is just as important for television as for the stage, and although the technique of use is completely different the form of the controls and the problems they pose tend (as more operational experience is gained) to become similar. The facilities provided by centralized lighting controls have led to direct control of lighting for picture quality. The lighting supervisor works the control himself and



4 *Part of the lighting control of a television studio*

sees the results on the producer's monitors (Fig. 4), any one of which he can select for closer examination on his own monitor. Development on these lines makes the lighting control a piece of key equipment. 621.316.72 : 628.973

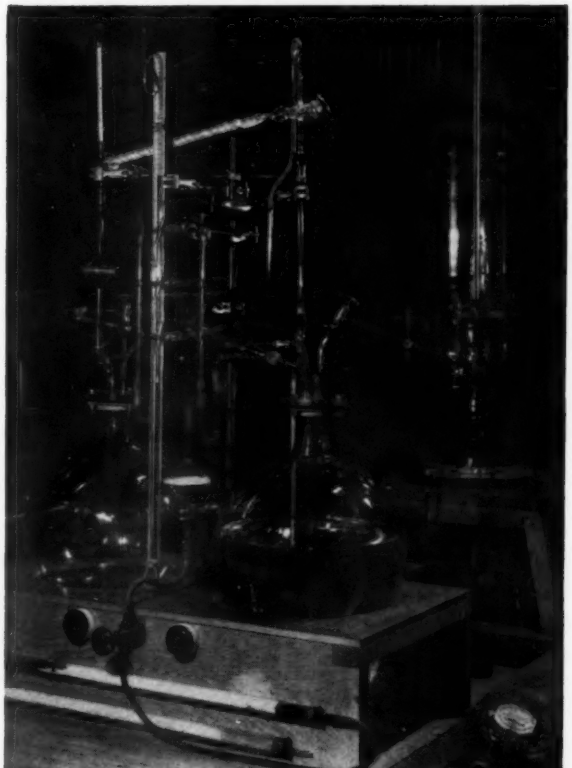
Impulse Breakdown of Oil

A short review of a Measurement and Control Section paper (No. 2408) entitled 'The Breakdown of Transformer Oil under Impulse Voltages', by R. Hancox, B.Sc.(Eng.), Ph.D., Graduate, and H. Tropper, Ph.D., Associate Member. The paper was published individually in September 1957, and it will be republished in Part A of the Proceedings. Dr. Tropper is, and Dr. Hancox was formerly, at Queen Mary College, University of London. Dr. Hancox is now at the Atomic Energy Research Establishment.

OIL OF VEGETABLE OR MINERAL ORIGIN HAS BEEN USED for electrical insulation since the beginning of the century, and it is therefore natural that the causes of electrical failure (or *breakdown*) in liquid dielectrics should have been the subject of much research. In recent years there has been a tendency towards the testing of small samples of carefully pretreated oil. This approach has the advantages that the test apparatus is small and easily handled and that the results may be obtained quickly. On the other hand, the very high breakdown strengths (1–3 MV/cm) recorded in these tests have not been obtained in practice in high-voltage equipment. An investigation was therefore undertaken to study the impulse breakdown of filtered and degassed transformer oil with higher voltages, and thus to find the increase in strength which might be obtained in practice by pretreatment of the oil and to show the relevance of small-scale tests to industrial requirements.

Previous workers who have studied the impulse breakdown of transformer oil with voltages in excess of 200 kV have used open test cells which usually consisted of a tank containing several hundred gallons of oil with a partially immersed high-voltage bushing to support the upper electrode. With such an arrangement the oil is open to contamination from dust and moisture in the atmosphere. For the present investigation it was possible to construct a totally-enclosed glass test cell in which 3-gallon samples of oil could be tested with impulse voltages of up to 600 kV. The electrodes were hemispheres, or hemispherically ended rods, of up to 3 inches diameter.

Solid impurities, together with a large proportion of the dissolved gas and moisture, were removed from the oil before it was tested. This was accomplished in a circulatory cleaning system by heating the oil and passing it through a sintered glass filter of 20–30 μ pore diameter into a vacuum. The oil could be filtered as many times as required before being admitted to the test cell, each cycle taking about five hours when the oil was heated to 70° C. The complete apparatus is shown in Fig. 1.

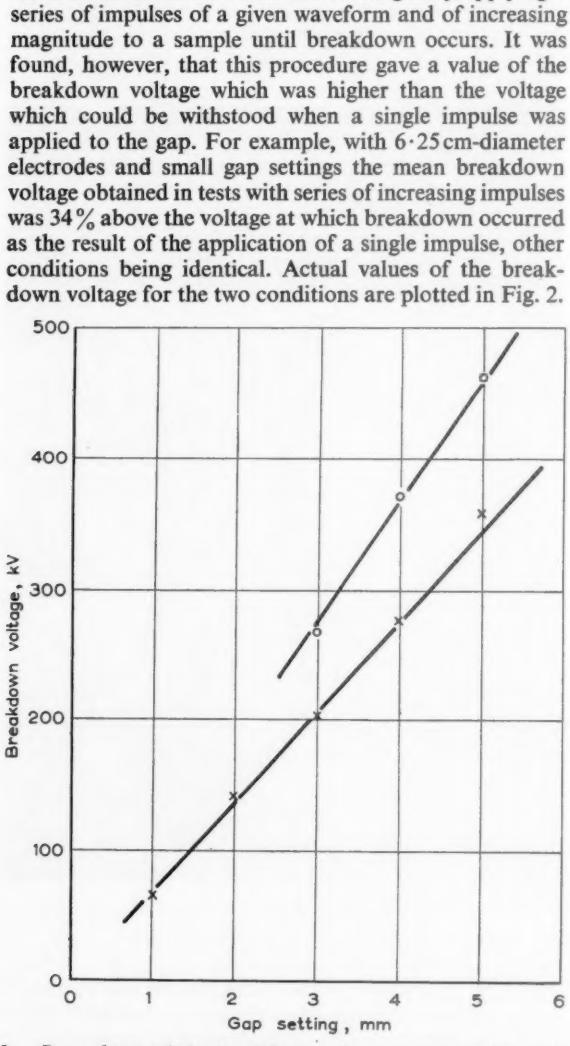


1 *The oil-cleaning system and test cell*

The authors found that the impulse breakdown strength of pretreated transformer oil was not an intrinsic property of the liquid, but depended upon several factors.

Many of the tests performed in the investigation were designed to show the extent to which the recorded breakdown strength was influenced by the test procedure and the electrodes employed. When oil of a given quality was tested, a wide range of values was obtained for the breakdown strength, depending on the test conditions, and it is obvious that not all of these correspond to the strength which might be expected under working conditions in high-voltage equipment. The investigation showed, therefore, some of the causes of the difference which is found between the breakdown strengths obtained in laboratory tests and under working conditions. Two examples are given below.

When performing a test, it is convenient to obtain an estimate of the mean breakdown strength by applying a series of impulses of a given waveform and of increasing magnitude to a sample until breakdown occurs. It was found, however, that this procedure gave a value of the breakdown voltage which was higher than the voltage which could be withstood when a single impulse was applied to the gap. For example, with 6·25 cm-diameter electrodes and small gap settings the mean breakdown voltage obtained in tests with series of increasing impulses was 34% above the voltage at which breakdown occurred as the result of the application of a single impulse, other conditions being identical. Actual values of the breakdown voltage for the two conditions are plotted in Fig. 2.

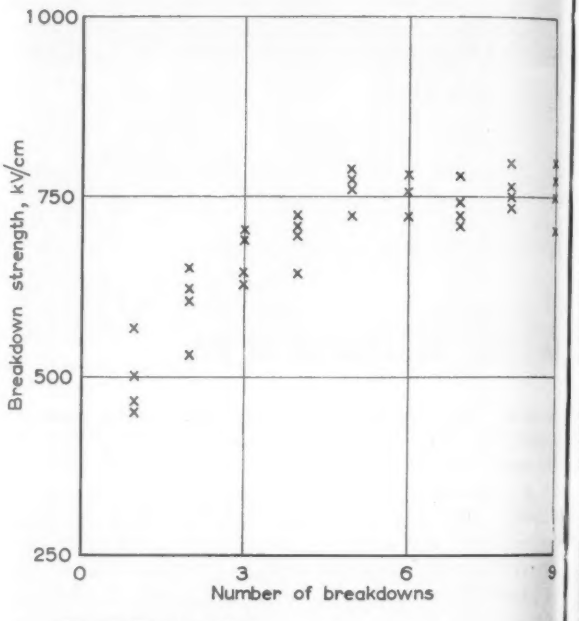


2 *Dependence of the breakdown voltage on gap setting and test procedure*

○ Breakdown voltage obtained with a series of impulses.
× Breakdown voltage obtained with a single impulse.

When a non-uniform field configuration with a negative point electrode was used, the difference was 46%.

Another effect was observed when a series of breakdown measurements were made with the same pair of electrodes. It was found that there was a gradual change in the recorded breakdown strength during the first few measurements. This conditioning effect has been reported by several investigators. It was observed that the mean breakdown strength after conditioning depended on the time between successive breakdowns. The results from four separate series of breakdowns, in which measurements were made with increasing impulses at 30 min intervals, are shown in Fig. 3, and it is seen that the mean



3 *The conditioning effect*

strength increased from 480 kV/cm to 750 kV/cm. When breakdowns were caused at 5 min intervals the mean strength after conditioning was 890 kV/cm.

It is seen from these results that values of the breakdown strength of transformer oil obtained in laboratory tests, in which series of increasing impulses were used or in which conditioning was observed, may be considerably higher than the strength obtained in practice where the oil is subjected only to occasional high-voltage impulses and where the first failure may result in the withdrawal of the equipment from service.

Several other aspects of the impulse breakdown of transformer oil have been studied, especially the dependence of the breakdown strength on the nature and pretreatment of the electrodes. Some of the results obtained have led to a further consideration of the theory of breakdown.

621.315.615.2:621.317.333.8

New Wind-Tunnel Drives

A short review of two Utilization Section papers (Nos. 2414 and 2415) entitled 'The Development of Variable-Speed High-Power Drives for Large Wind Tunnels' and 'A Variable-Frequency Power Installation for Large Wind-Tunnel Drives', by P. McKearney, O.B.E., Member, L. S. Drake, A.M.I.Mech.E., Associate Member, and E. G. Mallalieu, B.Sc., Associate Member. The papers were published individually in November 1957, and they will be republished in Part A of the Proceedings. The authors are with the Ministry of Works.

THE RAPID DEVELOPMENT IN AIRCRAFT PERFORMANCE brought about by the Second World War revealed the need in this country for larger supersonic wind tunnels, in which comparatively large-scale models could be tested under conditions which approached more closely to free-flight conditions. In addition to the new wind tunnels which the aircraft industry planned to build, the Government decided to extend its own testing facilities by building a number of larger tunnels at a new establishment near Bedford. Individual wind tunnel drives of the order of 50 000 h.p. were required, and, since the total installed horse power was expected to exceed 200 000, it was necessary to examine the power requirements of the different wind tunnels to be built and to decide how these requirements could best be met.

Ideally, the conditions under which a model is tested in a wind tunnel should be dynamically similar to the free-flight conditions of the body of which the model is a scale copy, but in practice it is rarely, if ever, possible to reproduce these conditions, and in high-speed tunnels it is the need to approach more closely to free-flight Reynolds numbers that has led to the development of high-power drives.

In a wind tunnel it is essential to maintain steady airflow conditions in the working section where the model under test is mounted. In subsonic tunnels the speed of the air stream is usually controlled by the speed of the compressor driving the air round the circuit; a wide range of operating speeds and accurate speed holding are required, a 5 : 1 speed range with an accuracy of 0·1% of set speed being typical. In supersonic tunnels, changes in the speed of the air stream are effected by changing the shape of the convergent-divergent nozzle through which the air accelerates to supersonic speeds before passing over the model, the speed of the compressor remaining unchanged. However, some control of compressor speed between, say, 70% and 100% of full speed is desirable in order to obtain better matching of the compressor and tunnel characteristics, thus saving power and reducing running costs. In large tunnels covering both subsonic and supersonic speeds, high-power drives with a wide speed range and accurate speed holding are required. An example of such a tunnel is shown schematically in Fig. 1.

Most wind-tunnel compressors are driven by electric motors, with Ward Leonard systems predominant for smaller subsonic tunnels, and with synchronous and induction motors used for the larger, more highly powered tunnels. However, in an establishment with several high-power electric drives, restrictions would have to be imposed by operating schedules designed to keep the maximum demand, and hence the maximum-demand

1 *General view of the supersonic wind tunnel at Bedford with 8 ft-square working section*

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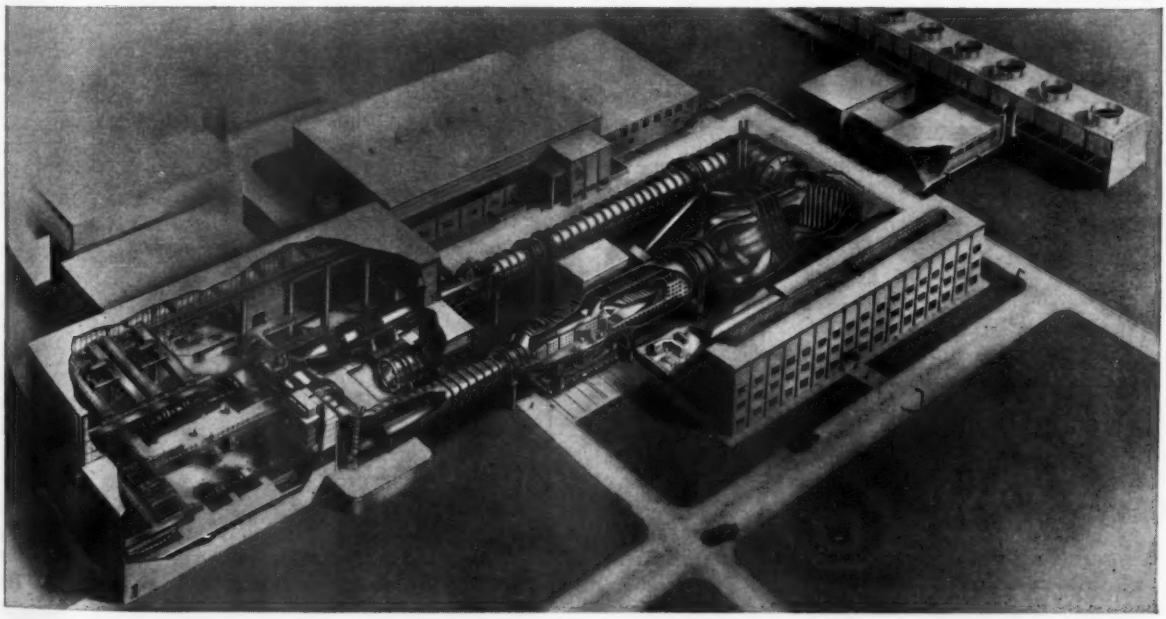
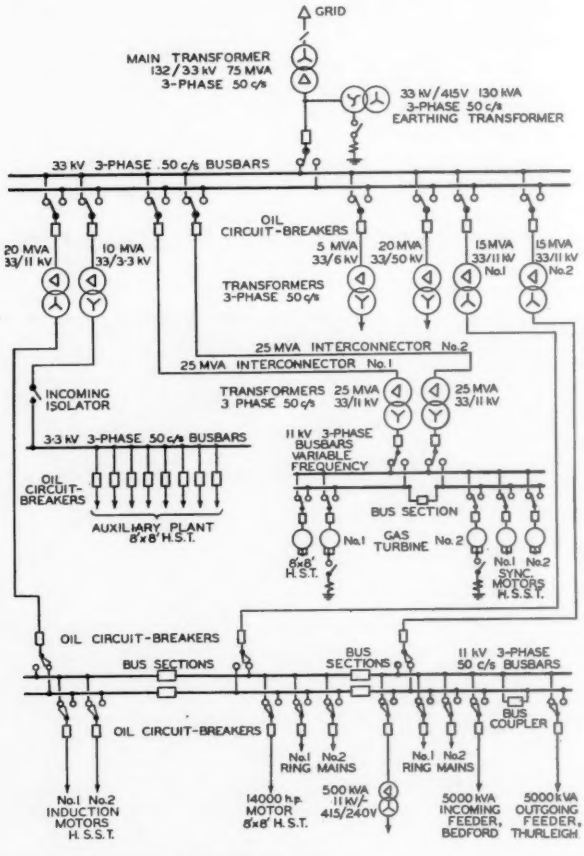


charges, within a given limit. This leads to a consideration of direct drives by prime movers or of site generation of electrical power. Of the two, the latter, based on a central generating station and with electrical distribution to the different wind-tunnel drives, is the more attractive, and, to obtain the full benefits of site-generated power for what are basically variable-speed drives, the power should be generated over a range of frequencies. The main driving motor for each wind tunnel can then be a synchronous motor which will run over a speed range proportional to the frequency range and at a fixed speed when connected to the Grid supply. Auxiliary motors will be required to run the drives up to synchronous speed.

At the Royal Aircraft Establishment, Bedford, it was decided to supplement the Grid supply with site-generated variable-frequency power. Gas turbines were chosen as the prime movers for this duty. Quick starting to full loads, ease of speed control and economy in space, water and operating staff were important factors influencing this choice for what is necessarily a comparatively low-load-factor plant.

Two 20 MW sets are being installed, the alternators


GRID
MAIN TRANSFORMER 132/33 kV 75 MVA 3-PHASE 50 c/s
33 kV/415V 130 kVA 3-PHASE 50 c/s EARTHING TRANSFORMER
33 kV 3-PHASE 50 c/s BUSBARS
OIL CIRCUIT-BREAKERS
20 MVA 33/11 kV
10 MVA 33/3·3 kV
TRANSFORMERS 3-PHASE 50 c/s
5 MVA 33/6 kV
20 MVA 33/50 kV
15 MVA 33/11 kV No.1
15 MVA 33/11 kV No.2
25 MVA INTERCONNECTOR No.2
25 MVA INTERCONNECTOR No.1
INCOMING ISOLATOR
TRANSFORMERS 3 PHASE 50 c/s
25 MVA 33/11 kV
25 MVA 33/11 kV
3·3 kV 3-PHASE 50 c/s BUSBARS
11 kV 3-PHASE BUSBARS VARIABLE FREQUENCY
OIL CIRCUIT-BREAKERS
AUXILIARY PLANT 8'x8' H.S.T.
BUS SECTION
No.1 GAS TURBINE No.2
6'x6' H.S.T.
No.1 No.2 SYNC. MOTORS H.S.S.T.
OIL CIRCUIT-BREAKERS
BUS SECTIONS
BUS SECTIONS
11 kV 3-PHASE 50 c/s BUSBARS
BUS COUPLER
OIL CIRCUIT-BREAKERS
No.1 RING MAINS
No.2 MAINS
No.1 No.2 RING MAINS
No.1 No.2 INDUCTION MOTORS H.S.S.T.
14000 h.p. MOTOR 8'x6' H.S.T.
500 kVA 11 kV/ 415/240V
5000 kVA INCOMING FEEDER, BEDFORD
5000 kVA OUTGOING FEEDER, THURLEIGH

2 *Electrical power distribution system*

H.S.T. = 8 ft × 8 ft high-speed tunnel.
H.S.S.T. = high supersonic speed tunnel.

being 2-pole machines operating over the frequency range 10–50 c/s with voltage proportional to frequency and equal to 11 kV at 50 c/s. Each alternator is connected via its own circuit-breaker to a double-busbar switchboard to which the Grid supply is also connected through two 25 MVA transformers. The outgoing feeders from this board supply the wind-tunnel driving motors with either variable-frequency power or Grid power, as required, and, since the bottom busbar is sectioned, it is possible to supply up to three independent loads simultaneously, as shown in Fig. 2.

The interconnection between the variable-frequency alternators and the Grid supply enables the alternators to reduce the site peak demand from the Grid by supplying part of the power either independently of the Grid, or (by arrangement with the supply authority) in parallel with the Grid.

The first wind tunnel to be connected to this Grid/variable-frequency network was the 8 ft high-speed variable-density tunnel, which covers both subsonic and supersonic speeds up to Mach No. 2·8 and which can test models of up to 6 ft wing span in its 8 ft-square working section.

The tunnel structure, which forms the closed circuit for the circulating air, is a large steel pressure vessel generally circular in cross-section and varying in diameter from 20 ft to 47 ft, the complete circuit following a rectangular course of length 820 ft along the centre line.

The compressor is a 10-stage axial machine, which, for more efficient working at the lower pressure ratios, can be run as a 4-stage machine by replacing the 6 high-pressure stages by a dummy casing, both compressor casings and dummy casing forming part of the pressure shell when in circuit.

The air from the compressor is cooled before entering the working section, which is a rectangular structure within the pressure shell. Its side walls are fixed, and the top and bottom walls are flexed to form the convergent/divergent nozzle. The flexible walls are made of 1-inch steel plates 64 ft long × 8 ft wide. Each plate is supported and flexed by 30 pairs of screw jacks driven by hydraulic motors controlled by sensitive valves, which are in turn controlled electrically through punched tapes and modified telegraph-type tape readers.

The model under test is mounted at the downstream end of the working section. It is observed through a periscope and by closed-circuit television. A Schlieren light system displays the air-flow pattern round the model. The pressure distribution is measured by orifices connected to manometers, and the forces on the model are measured by strain gauges. After passing over the model, the air passes through the supersonic and subsonic diffusers to reduce its speed efficiently before entering the compressor inlet.

The main compressor is driven by a direct-coupled 68 000 h.p. 8-pole synchronous motor (shown during erection in Fig. 3), and, through a gear box, by two 6 000 h.p. d.c. motors in tandem (shown in Fig. 4). The latter are supplied from two similar machines acting as

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3 *Erection of the 68 000 h.p. synchronous motor for the 8 ft high-speed wind tunnel*

generators in a series loop as a Ward Leonard system (Fig. 5).

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4 *Driving motors for the main compressor of the 8 ft high-speed wind tunnel*

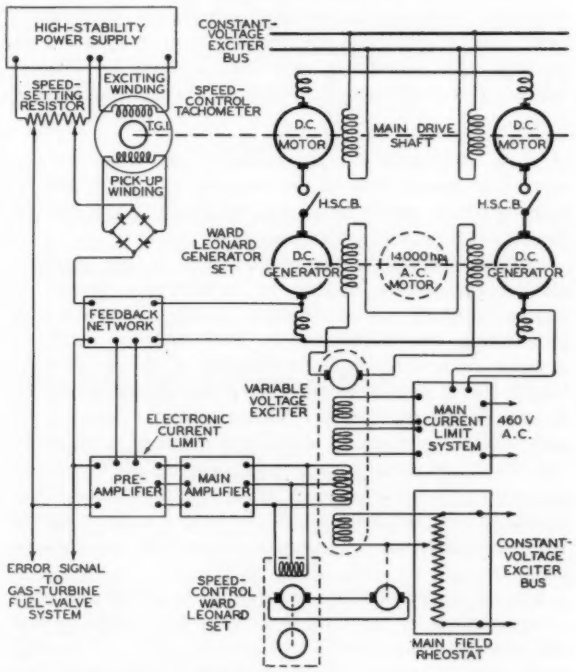
The 68 000 h.p. synchronous motor can be seen at the rear.

The compressor may be driven in any one of three ways:

(1) By d.c. motors alone over the complete speed range of 150–750 r.p.m. (corresponding to 10–50 c/s of the 68 000 h.p. motor), with the 68 000 h.p. motor electrically disconnected and with the tunnel air density (which can be varied from 0·1 to 4·0 atm absolute) adjusted to keep the total drive power within the capacity of the d.c. machines.

(2) At constant speed by the 68 000 h.p. motor connected to the Grid supply, using the d.c. motors to run the drive up to synchronizing speed at reduced tunnel air density, and, after synchronizing, to provide additional power.

(3) By the 68 000 h.p. motor connected to the two 20 MW gas-turbine alternators, the d.c. motors again running the drive up to synchronizing



5 *D.C. speed-control system*

8 ft high-speed wind tunnel.

speed (10 c/s) and thereafter providing fixed torque from the Grid-powered Ward Leonard system over the full speed range.

When the d.c. motors are used to drive the compressor, an automatic control system is provided to control the excitation of the d.c. generators in the Ward Leonard

system. This control system is designed to hold the compressor speed to within $\pm 0{\cdot}1\%$ of set speed and is based on an established method, namely that of the voltage comparison of the output of a tacho-generator coupled to the drive shaft with the setting of a potentiometer fed from a constant-voltage source. When the compressor is driven by the variable-frequency alternators and the d.c. motors, the speed-control system automatically adjusts the gas-turbine fuel-valve settings to cancel any speed error and to maintain the d.c.-motor armature current at a preset figure.

533.6.07: 621.316.718: 621.316.726: 621.34

Speed Control of Large Wind Tunnels

A short review of a Utilization Section paper (No. 2501) entitled 'Speed Control of Large Wind Tunnels, with particular reference to the R.A.E. 8ft × 8ft High-Speed Wind Tunnel', by L. S. Drake, A.M.I.Mech.E., Associate Member, J. A. Fox and G. H. A. Gunnell, Associate Member. The paper was published individually in December 1957, and it will be republished in Part A of the Proceedings. Mr. Drake is with the Ministry of Works; Messrs. Fox and Gunnell are with the English Electric Co.

IT IS A FUNDAMENTAL REQUIREMENT OF WIND-TUNNEL work that the air flow in the working section should be held constant while readings are being taken of the forces on the model under test.

In subsonic work, the air velocity in the working section is directly related to compressor speed. In supersonic work, speed setting is mainly concerned with positioning the shock wave, and holding accuracy depends on restraining the movement of the shock wave which forms at air speeds above the speed of sound. In both instances, therefore, accurate speed control of the compressor is necessary, and this is required to be about $\pm 0{\cdot}1\%$ of set speed over a wide speed range. There are, however, special features in the speed control of wind-tunnel drives which enable this accuracy to be achieved with conventional equipment if special precautions are taken.

Unlike most industrial drive control, where normally compensation is required for large and rapid power changes, the control system of a wind tunnel has to deal with comparatively slow changes and with conditions held stable at the time when the greatest speed accuracy is required. While very accurate control can be achieved by an operator manipulating a fine rheostat in accordance with the readings of the extremely accurate instruments used in wind-tunnel work, the strain over a long period of working is prohibitive, and automatic speed-holding equipment is a necessity.

The essentials of a control system for this purpose comprise a stable speed reference and a speed-error detecting network, the output of which is amplified and applied to the driving motors so as to compensate for the disturbance causing the speed divergence.

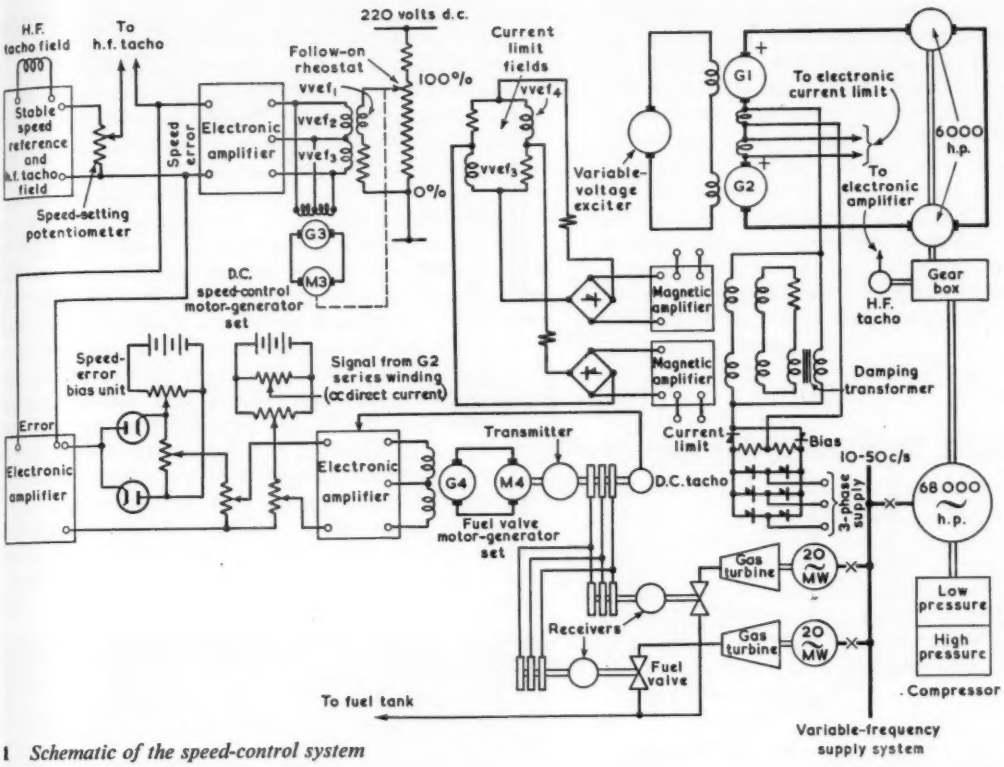
For the 8 ft-tunnel-drive control system, a number of speed-error detecting systems using the preferred single-knob control and capable of providing the specified accuracy were considered. These included phase and frequency comparison methods, and special consideration was given to the role of the gas-turbine control. It was decided that a voltage comparison system incorporating a highly stabilized and self-compensated voltage reference and tacho-generator field would provide the best method of control for this purpose. Fig. 1 shows a diagram of the control system finally developed.

As described in detail in the associated paper *A Variable-Frequency Power Installation for Large Wind-Tunnel Drives*, the composite drive for the 8 ft tunnel comprises a 68 000 h.p. synchronous motor supplied from two gas-turbine-driven variable-frequency alternators and two d.c. motors each of 6 000 h.p. connected in a series loop to two similar machines operating as generators under Ward Leonard control. The drive can be run at variable speed by the d.c. motors alone or combined with the a.c. motor fed from the variable-frequency supply. There are thus two control systems, for the a.c. and d.c. machines respectively, and, since it is necessary to avoid conflict between them, the d.c. machines were chosen for master control, with the gas turbines providing a follow-on control. This choice was made on account of the faster response and inherent low regulation of the Ward Leonard system.

In the system illustrated in Fig. 1, the rectified and smoothed output of a high-frequency tacho-generator is compared with a highly stabilized reference voltage to give a voltage proportional to speed error. After the addition of stabilizing signals, the error voltage is amplified and applied to the push-pull fields of a variable-voltage exciter so as to oppose or assist the main excitation of the Ward Leonard generators by a maximum of 10% of full field. In addition, the error signal operates a follow-on rheostat which adjusts the main excitation to reduce the speed error and the electronic output to zero. Hence, under steady-state, or near-steady-state, conditions, the failure of an electronic component will not cause a major change in drive speed.

Control of the gas turbines, and consequently of the a.c. motor, is carried out on the turbine fuel valves by a composite signal which incorporates the speed-error signal and a signal proportional to the current flowing in the Ward Leonard loop. The normal action of the gas turbines, therefore, is to unload the d.c. machines, leaving them on light load and available for further correction of speed changes.

The stability of the master control is shown by mathematical analysis to require a combined integral and proportional system having a gain of 40 with a stabilizing feedback over the whole loop. The transient analysis of the system shows (Fig. 2) that the response to a small step of reference gives a time to crossover of 2·7 sec, a 10% first overshoot, and a settling time of 10 sec.

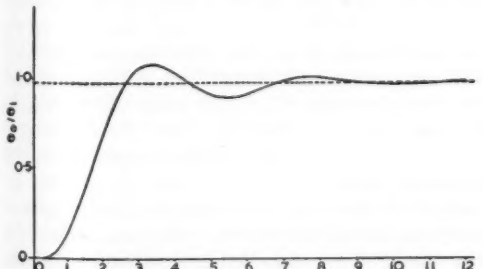


1 *Schematic of the speed-control system*

Tests carried out on the d.c. portion of the drive, which is the master control, showed that in the range 75–750 r.p.m. the drive speed was held better than $\pm 0{\cdot}1\%$ over periods of 30 min. One test of five hours' duration at 600 r.p.m. showed no tendency to deviate outside the $\pm 0{\cdot}1\%$ limits.

An electronic counter gated over 10 sec periods was used to give an accurate measurement of shaft speed for these tests. The counter input was obtained from a photo-electric pick-up, the light source of which was interrupted by 600 steel pegs fixed in the rim of the brake wheel on the main compressor shaft, so that at a speed of 750 r.p.m. the total count was 75 000. By this means a possible speed change of $0{\cdot}1\%$ at this speed is represented by a change of 75 in the count.

621.316.718.5 : 533.06.7

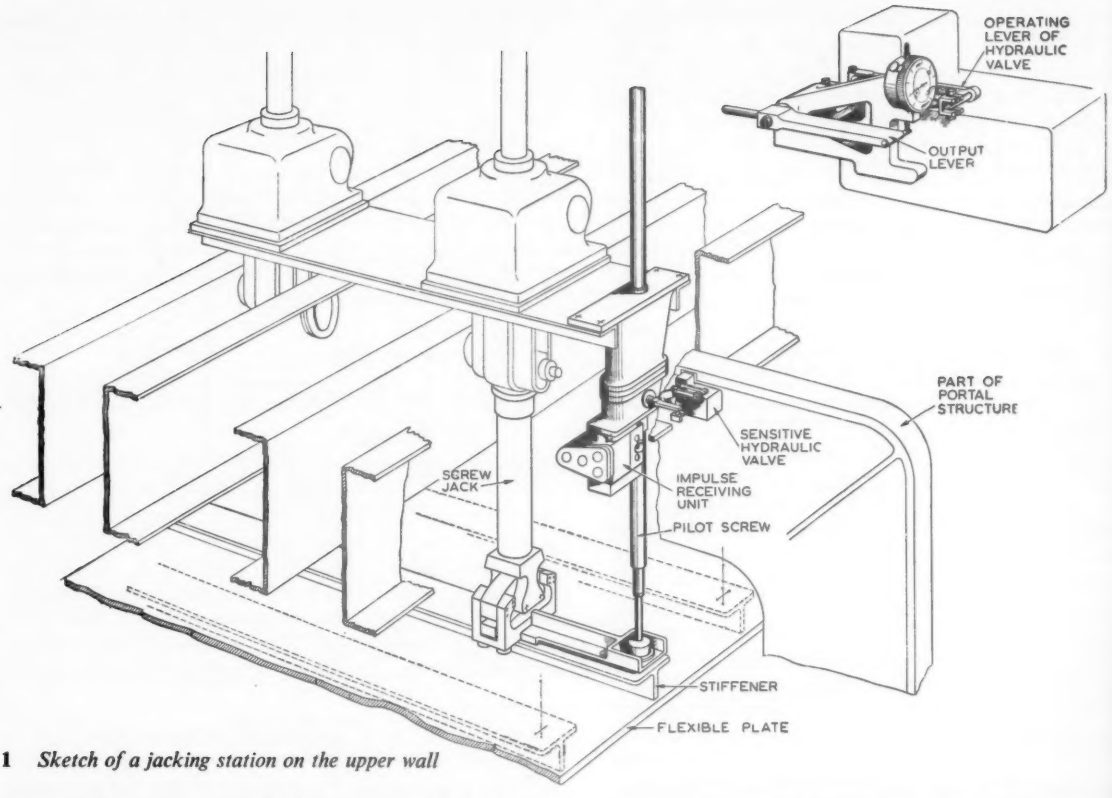


2 *Response to step input of reference*
θ_i is the input angular velocity (rad/sec).
θ_o is the output angular velocity.

Flexible Wind-Tunnel Walls

A short review of a Utilization Section paper (No. 2524) entitled 'Automatic Setting of the Flexible Walls of a Large Wind Tunnel', by T. Barnes, A.M.I.Mech.E., and C. R. Dunham, M.A., Associate Member. The paper was published individually in December 1957 and it will be republished in Part A of the Proceedings. Mr. Barnes is with the Ministry of Works; Mr. Dunham is with the General Electric Co.

THE NEW HIGH-SPEED WIND TUNNEL AT THE ROYAL Aircraft Establishment, Bedford, is designed for operation at air speeds up to 2·8 times the velocity of sound. The cross-section of the air passage, where a model is tested, is 8 ft square; sufficient to cater for models with wing span up to 6 ft. Ahead of the test region, the air passage is shaped to form a convergent-divergent nozzle to develop supersonic airflow, and, since this nozzle has been made adjustable, the air speed can be varied continuously throughout the supersonic

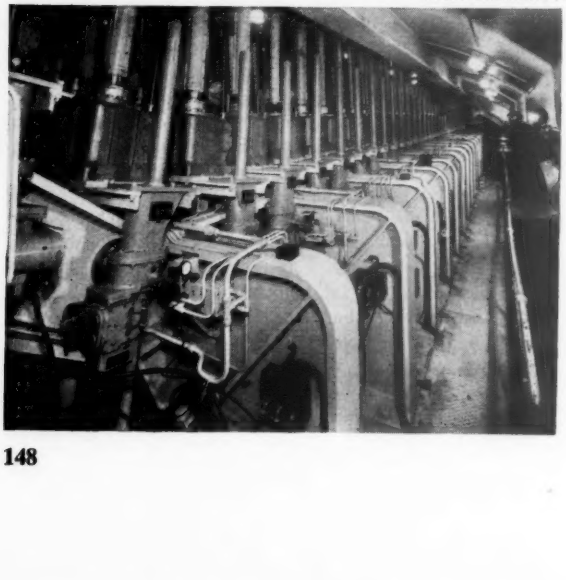


1 *Sketch of a jacking station on the upper wall*

range of the tunnel. The flexible nozzle comprises two 65 ft × 8 ft steel plates, 1 in. thick, which slide between two side walls fixed 8 ft apart. The plates are curved to the required shape for any particular Mach number by a series of hydraulically actuated screw jacks spaced at intervals of 2 ft along their length. Portal frame structures built up from the side walls (above and below) provide support for the jack trunnions, and make the nozzle a self-contained unit within the cylindrical pressure shell of the tunnel.

2 *Jacking stations on the upper wall, showing pilot screws*

General Electric Co.



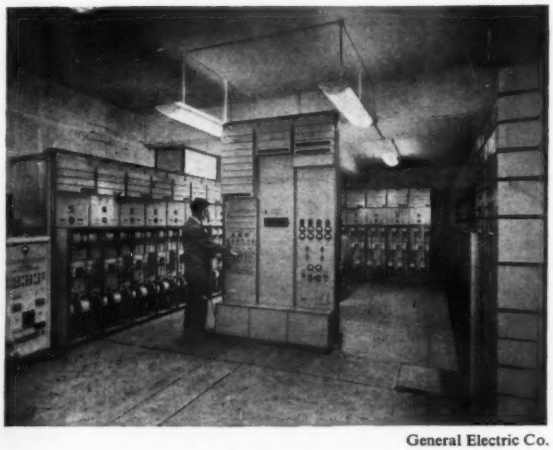
The requirements for the control of air speed call for great accuracy in setting the jacks, since a departure from the proper wall shape may give rise to non-uniformity of the air flow at the model test region, and may also be accompanied by dangerously high bending stresses in the flexible plates, which are already fairly highly stressed when at their designed curvatures. In order to obtain the close control of positioning (i.e. to minimize the effects of strain and thermal expansion in the jack legs), a pilot lead-screw is fitted at each jacking station as shown in Figs. 1 and 2, and this sets up the required datum accurately. The hydraulic-jack motor is controlled by a valve, whose opening is determined by the difference in extension of the pilot screw and the jack legs, and drives the latter to follow the movements of the pilot, and therefore to assume its required setting irrespective of strain, etc.

The authors' main concern is with the development of the pilot lead-screw assemblies, and the means for operating them from outside the pressure shell in accordance with a predetermined programme. Starting with the flexible plates curved to form a nozzle suitable for Mach number 1·0, the shape may be progressively changed to that of a nozzle for Mach 2·8. The complete action takes about 40 min, and correspondingly less if

an intermediate air speed is required; the action may of course be reversed to reduce the air speed.

The information for the programme is provided in the form of punched paper tape which is read by a number of telegraph tape-readers operating in step together. One tape reader deals with one jacking station on the upper flexible wall and one on the lower wall; thus thirty tape readers are needed for operating the nozzle. Perforations in the tape correspond to discreet movements of 0·0025 in. of the pilot screw (or of 0·00125 in. for some screws near the downstream end of the nozzle where the total movement is less). At each perforation, the tape reader delivers an electric impulse to an *impulse-receiving unit* inside the tunnel and the nut of the pilot screw is rotated through 0·01 revolution; this is brought about because the impulse releases a clutch which applies, for one revolution, the drive from a constantly revolving induction motor to the nut (a second one-revolution clutch is provided for retracting the nut).

In order to prevent any overstressing of the plate due to false or missing impulses or to failures in equipment, there is a second set of thirty tape readers reading identically punched tapes, and these operate monitoring units outside the tunnel (Fig. 3). Correspondence between these and the impulse receiving units inside the tunnel is continuously checked by relays whose circuits pass through cam-operated contacts on both units, and any failure of them to keep in step is at once detected; interlocks come into action and stop further movement of the control system until the defaulting member has been rectified. Considerable attention has been given to providing means for locating faults and correcting them with as little delay as possible, so as to prevent undue waste of tunnel operating time.



General Electric Co.

3 *Equipment room, housing tape readers and monitoring units*

It will be apparent that the development of this control system has been a fairly large undertaking in design, manufacture and installation, and it has posed a number of interesting problems. The circuit arrangements have been based almost entirely on the use of well-known and well-tried apparatus common in automatic telephony and telegraphy. However, the adaptation of this equipment to the present project has involved considerable high-precision mechanical design work, backed up by careful and prolonged testing.

The nozzle-setting gear has been in operation since the commissioning of the tunnel some six months ago, and is proving satisfactory in meeting the operational requirements. The flexibility obtained from the adoption of punched tape as the information store has been found to be advantageous in permitting final refinements to the nozzle shape to be introduced without difficulty and in a very short time.

621–526 : 533.06.7

Mercury-Arc-Rectified Winder Drives

A short review of a Utilization Section paper (No. 2324) entitled 'D.C. Winder Drives using Mercury-Arc Rectifier/Inverters', by L. Abram, B.Sc.(Eng.), Associate Member, J. P. McBreen, Associate Member, and J. Sherlock, B.Sc.(Eng.). The paper was published individually in February 1957, and it will be republished in Part A of the Proceedings. The authors are with the Metropolitan-Vickers Electrical Co.

THE HIGH EFFICIENCY OF MERCURY-ARC RECTIFIERS HAS led to their use extensively in other fields, but their application to winder drives has been very limited, mainly owing to the lack of a suitable control system.

The normal duties imposed by winding engines are such that the torque can either remain positive during the whole cycle or change from positive to negative at some time during the cycle. In addition, auxiliary duties and manoeuvring operations may be required at different speeds and loads. Thus, an electric drive for winders must be capable of dealing with loads up to the maximum at all speeds, in either direction, up to the designed full speed. Furthermore, the policy of concentrating windings in a comparatively few main shafts, which are utilized to the full, has called for improved performance from winder control systems to enable the winding cycle to be adhered to more closely.

This has resulted in the development of closed-loop control systems, which are applied to winders suitable for either automatic or cyclic-manual operation. Under varying load conditions, these control systems must be capable of regulating the speed of the winder to an accuracy of $\pm 0{\cdot}5\%$ of full speed, and of maintaining the acceleration and retardation periods to within $\pm 10\%$ of the no-load figures. In addition, the response of the system as a whole must be sufficiently fast to enable cam gear to be used to retard the winder to a safe speed as the conveyance approaches the terminal points of the wind.

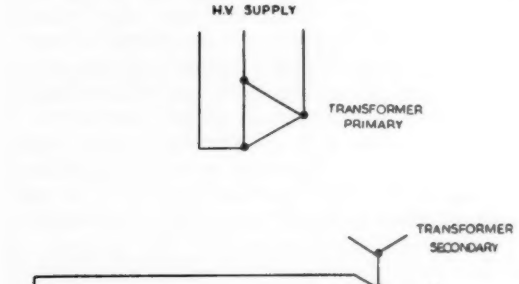
In the past, electric winder drives have been provided by using either a 3-phase a.c. induction motor or a d.c.

motor supplied from a motor-generator set and controlled on the Ward Leonard principle. Of these, the induction motor has proved attractive because of the relative simplicity and robustness of the machine, but the auxiliary gear to control the direction of rotation and the speed of the machine is fairly complicated. Further disadvantages are that, at reduced speeds, the efficiency of the installation is greatly reduced and that regenerative braking can be achieved only at speeds above the normal full speed. Thus retardation of the winder or running at reduced speeds with descending loads can be performed electrically only by using reverse current or dynamic braking, both of which absorb power from the supply system. Finally, the non-linear characteristics of the a.c. machine make it inherently unsuitable for closed-loop control, and, as yet, no system of control for an a.c. drive has been produced which meets all the requirements mentioned above.

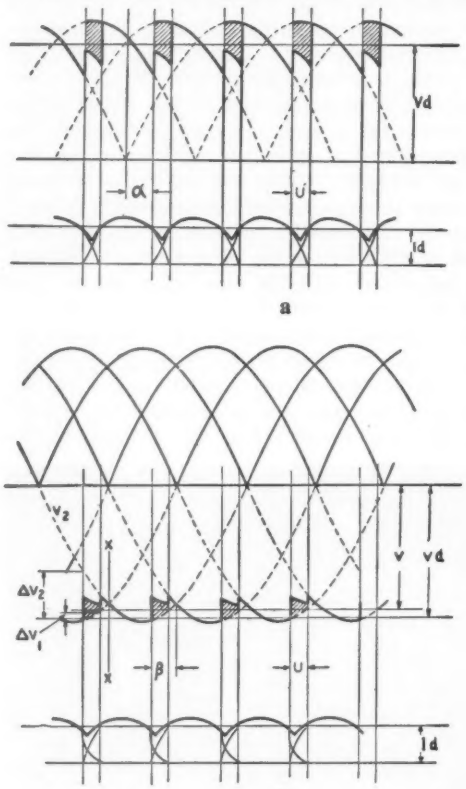
Most of these disadvantages are overcome by using a d.c. motor controlled on the Ward Leonard principle. This type of machine lends itself to direct-coupled drives with the consequent omission of gears, whilst the introduction of a motor-generator set permits the use of systems which can be used to provide power-factor correction and to reduce the peak loads imposed on the supply system. But the use of a motor-generator set is itself a disadvantage because it is an expensive item of equipment requiring special foundations and buildings and additional maintenance.

Consideration has been given to the use of mercury-arc rectifiers in order to overcome the disadvantages of the a.c. and Ward Leonard drives. The greater efficiency of the rectifier results in reduced power consumption during winding operations, i.e. a consumption between 44% and 85% of that of an a.c. drive, and between 85% and 97% of that of a Ward Leonard drive. In the latter case, the saving may be more marked if there are lengthy periods when no winding occurs, because the light-load loss of a mercury-arc rectifier is considerably lower than that of an equivalent motor-generator set.

Since the mercury-arc rectifier is a unidirectional current-carrying device, the reversal of the direction of power flow is achieved by reversing the direction of the voltage. Thus, when the winder motor is regenerating, the current is made to flow in the rectifier when the applied anode voltage is negative. At the same time the back e.m.f. of the motor must be reversed with respect to the rectifier voltage.



1 *Connections of rectifier/inverter*

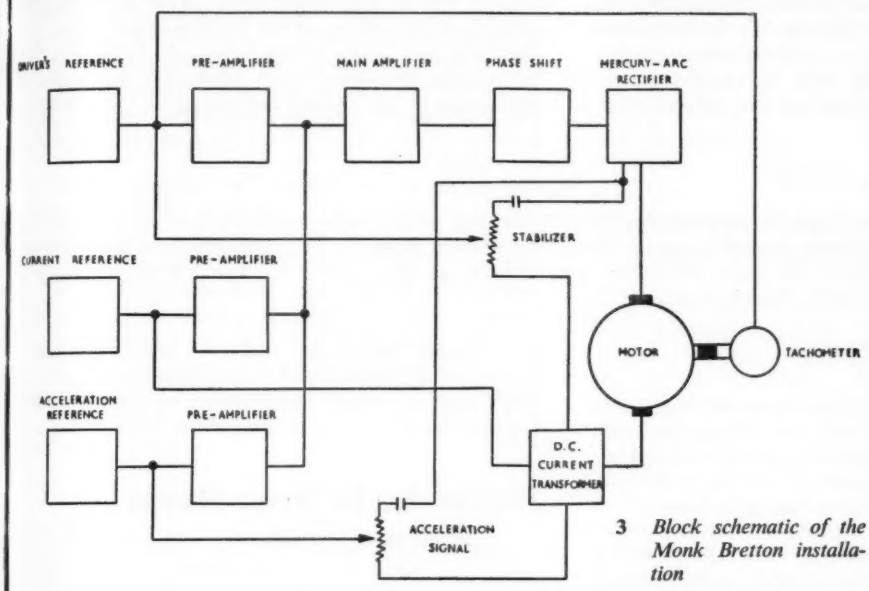


2 *Voltage and current waveshapes*

a Rectifying, with grid control.
b Inverting.

V = Mean inverter phase voltage.
V_d = Mean d.c.-circuit voltage.
I_d = Direct load current.
α = Angle of firing delay.
β = Angle of firing advance.
u = Angle of overlap.

The method by which this is achieved is shown in Fig. 1. Only one rectifier is used, and the required reversal is effected either by armature contactors or by reversal of the motor field. Practical limitations in contactor design preclude the use of armature contactors on any except the smaller winders. Although the system has been used on the first installation in Britain, at Monk Bretton No. 3 shaft, it is felt that improved results could be obtained by using field reversal.



3 *Block schematic of the Monk Bretton installation*

The operation of a mercury-arc rectifier is well known, and Fig. 2*a* shows the current and voltage waveshapes when grid control is employed to reduce the average d.c. output. For inversion, the firing of the anodes is delayed beyond the zero voltage for rectification, as shown in Fig. 2*b*, from which it is evident that there is a limit beyond which the firing point must not be delayed. This limit results in a transformer 10–20% larger than that necessary for the equivalent free-firing rectifier duty, and it always involves operation during rectification with some firing delay.

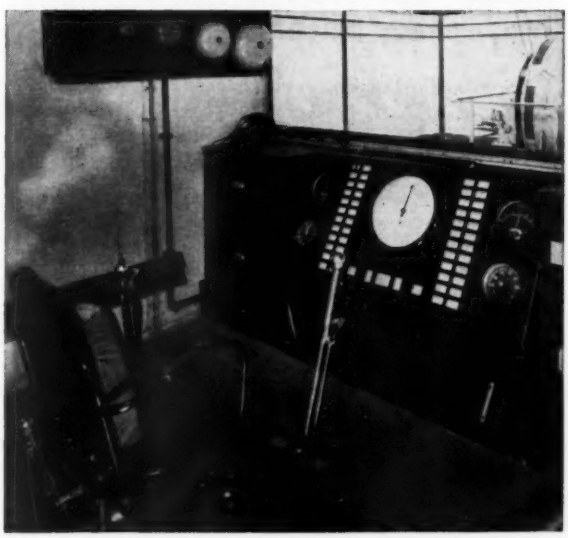
The grid control is achieved by firing pulses which overcome the d.c. bias holding the grids negative with respect to the cathode. These pulses, which are of the same frequency as the anode voltage, are derived from peaking units which give a steep-fronted output voltage. The supply to these units is derived from a static phase-shifting unit, and, by varying the control current of the latter, the phase angle of the voltage applied to the grids can be varied.

It will be apparent that, with grid control, the d.c. waveshapes will be distorted; also, at reduced direct voltages there is a tendency for the current to become discontinuous. However, such discontinuity is avoided by the use of reactors as shown in Fig. 1. These reactors also serve to smooth the ripple in the output voltage and thus to reduce the effect of this type of supply on motor commutation and heating, although tests and practical experience indicate that these effects are not serious.

A rectifier tends to draw a distorted current from the a.c. system, made up of a fundamental and various harmonics, the maximum values of which are specified in Appendix F of B.S. 1698: 1950. In passing through the a.c. system these harmonic currents set up corresponding harmonic voltages in the network, and the possibility of interference from these harmonics must be taken into account when determining the number of phases and transformer connection for each installation.

The rectifier winder, with its inherent regulation and continuous availability of torque, is eminently suitable for closed-loop control. A block diagram of the control scheme is shown in Fig. 3; it consists of a speed control with overriding current limit and acceleration (or retardation) limit. The main amplifier of the servo system is an auto-self-excited transductor, the output of which

4 *Control chair and instrument panel of the installation at Monk Bretton*



is fed to the control windings of the phase-shift circuit. The pre-amplifier consists of three series transductors with separate control windings—an arrangement which avoids interaction of the separate controls. These magnetic amplifiers have been chosen in preference to electronic or rotary amplifiers because of their reliability.

The system described above has been in operation on the 300 h.p. winder at Monk Bretton No. 3 Shaft since early in 1955. Fig. 4 shows the control position of this installation. Tests carried out have indicated that the accuracy of the speed control and of the various overriding limits are within the requirements mentioned above. Although cam gear was not originally installed, steps have now been taken to have this added because the response of the system is adequate.

The effect of the rectifier operation on associated equipment, e.g. a 10 kVA auxiliary transformer and a 250 h.p. a.c. fan motor, has also been tested and no adverse effects have been noted. Finally, a harmonic analysis of the voltage on the 11 kV busbars, at which the electricity authority's supply is brought into the colliery, has shown that very small additional harmonics are introduced by the rectifier equipment. 621.34:621.314.6

SYNOPSES OF PAPERS

The following are synopses of papers published in the *Proceedings* which have not been read at an Institution meeting and which have not been described under 'Short Reviews of Papers'. They are included here primarily for reference. The papers have not been published individually, as have those for reading at meetings, but reprints of them will be available shortly (see p. 155).

Bandwidth-Halving Coder

A synopsis of a Radio and Telecommunication Section paper (No. 2454) entitled 'A Coder for Halving the Bandwidth of Signals', by A. R. Billings, B.Sc., Ph.D., Graduate. The paper is published this month in Part B of the Proceedings. The author is at the University of Bristol.

IT IS SHOWN THAT IT IS POSSIBLE TO CODE A CONTINUOUS message of finite bandwidth into a continuous signal of smaller bandwidth, provided that sufficient signal power is available. A possible system capable of performing this coding is described, and it is shown that the exchange of bandwidth for power occurs in the same manner as for Shannon's ideal system. 621.376.56 : 621.391

Parallel Operation of Two Synchronous Machines

A synopsis of a Supply Section paper (No. 2423) with the above title, by J. H. Walker, M.Sc., Ph.D., Member, and N. Kerruish, M.A. The paper was published in February 1958 in Part A of the Proceedings. The authors are with the British Thomson-Houston Co.

THE PAPER DERIVES THE EQUATIONS REQUIRED IN THE prediction of the steady-state characteristics of an alternator supplying a synchronous motor, which is of particular interest in electric ship propulsion. These equations are valid for any degree of saliency and any value of synchronous reactance in either machine. Since considerable labour is required in the numerical evaluation of the equations, the power, terminal voltage, armature current and pole angles at pull-out, as functions of the machine synchronous reactances, are given in the form of tables or families of curves. A curve is given showing the variation of the pull-out power with saliency, and another shows the extent to which the pull-out power of a combination of two machines is reduced compared with the values which would be obtained if either machine were running on an infinite busbar. 621.313.3

Flicker due to Space Charge

A synopsis of a Radio and Telecommunication Section paper (No. 2493) entitled 'Space Charge as a Source of Flicker Effect', by C. S. Bull, Ph.D., Associate Member. The paper is published this month in Part B of the Proceedings. The author is at the College of Technology, Birmingham.

THE CAPACITIVE EFFECT OF SPACE CHARGE IN A SPACE-charge-limited or saturated diode is well known, but it has not been taken into account in forming a theory of the fluctuations.

The capacitive current evoked from the space charge by the fluctuations in anode voltage consists of the motion of free electrons and is therefore itself subject to fluctuations. By including these it is found that three distinct types of fluctuation exist together. One is the shot noise, depending in the well-known way on the effect of space charge in controlling the anode current. The second is an enhancement of the shot noise by an amount dependent on the ratio between the capacitance due to space charge and the total circuit capacitance. It is like the shot noise in that the total mean-square voltage is proportional to the resistance of the anode circuit. It is, however, unlike the shot noise in that it varies with anode voltage even when the valve is saturated. The third is a flicker effect dependent on the magnitude of the electronic capacitance, and not requiring the postulation of a lifetime of metastable states on the electrodes.

In the course of the paper a general form of Campbell's theorem is given, together with a discussion of the way in which the theoretical considerations must be made

match the experimental conditions. Also, new probability generating functions are put forward. 621.385.2

Constant-Resistance Amplitude Equalizers

A synopsis of a Radio and Telecommunication Section paper (No. 2464) entitled 'An Approach to the Design of Constant-Resistance Amplitude Equalizer Networks', by J. S. Bell, Graduate. The paper is published this month in Part B of the Proceedings. The author is with Blackburn and General Aircraft Ltd.

IT IS OFTEN DESIRABLE TO CORRECT OR TO ADJUST THE amplitude/frequency response of a network to meet certain stated requirements. Although it is usually not difficult to calculate the insertion loss of a correcting network, the inverse is rather more difficult. The paper suggests a method of designing constant-resistance amplitude equalizers to give a desired slope over the working range concerned. A typical example is given in order to illustrate the method of adjusting the response of a velocity-type pick-up over part of the audio-frequency spectrum. 621.372.5

Wide-Band Waveguide Filters with Short Linear Tapers

A synopsis of a Radio and Telecommunication Section paper (No. 2547) with the above title by G. Craven. The paper is published this month in Part B of the Proceedings. The author is with Standard Telecommunication Laboratories Ltd.

BROAD-BAND WAVEGUIDE FILTERS, WHICH OBTAIN A band-pass characteristic by combining low-pass and high-pass networks, are discussed. Filters of this type do not, in general, match the impedance of standard guide. A method of design, in which simple linear tapers are employed to effect matching, is described. The design procedure is illustrated in a typical example and experimental results are given. 621.372.852.1

High-Voltage Measurement

A synopsis of a Measurement and Control Section paper (No. 2543) entitled 'The Measurement of High Voltages with Indicating or Recording Instruments', by G. W. Bowdler, M.Sc., Associate Member. The paper will be published in Part A of the Proceedings. The author is at the National Physical Laboratory.

THE PAPER REVIEWS THE METHODS BY WHICH THE MEAN, r.m.s., or peak values of voltages ranging from 10 kV upwards may be measured by indicating or recording instruments to an accuracy within about 1%. Most of the methods used either a low-range high-impedance voltmeter or cathode-ray oscillograph in conjunction with a voltage divider or a milliammeter in series with a high impedance.

Voltage dividers suitable for use with direct, alternating and impulse voltages are considered, and, amongst the measuring instruments, the diode peak voltmeter is discussed in some detail. High-range electrostatic voltmeters are also considered.

It is concluded that there are always at least two different methods by which a particular type of voltage may be measured. 621.317.32

Microwave Measurements of Surface Impedance

A synopsis of a Radio and Telecommunication Section paper (No. 2467) entitled 'An Instrument for the Measurement of Surface Impedance at Microwave Frequencies', by A. E. Karbowiak, Ph.D., B.Sc.(Eng.), Associate Member. The paper is published this month in Part B of the Proceedings. The author is with Standard Telecommunication Laboratories Ltd.

A THEORY IS GIVEN OF AN INSTRUMENT FOR THE MEASUREment of surface impedance at microwave frequencies.

Two prototype instruments—one for 6 Gc/s and one for 34 Gc/s—are described, and the measurement procedure is explained. Basically the surface impedance is deduced from the resonant conditions of the cavity operated simultaneously in H_{01}- and E_{11}-modes. In particular, the cavity bandwidth is a measure of the surface resistance, and the surface reactance is deducible from the separation between the H_{01} and E_{11} responses.

As an illustration of the use of the instruments a number of experimental results are cited. 621.317.73.029.64

Ferrite Loss-Factors at 10 Gc/s

A synopsis of a Radio and Telecommunication Section paper (No. 2518) entitled 'Measurement of Ferrite Loss-Factors at 10 Gc/s', by C. M. Srivastava, M.Sc., and J. Roberts, B.Sc.(Eng.), Associate Member. The paper is published this month in Part B of the Proceedings. Mr. Roberts is, and Mr. Srivastava was, at Imperial College, University of London; Mr. Srivastava is now at Benares Hindu University, India.

THE ANALYSIS IS PRESENTED OF THE LOSSES ARISING IN A rectangular cavity containing ferrite slabs which extend the full length of the cavity. The loss factors associated with the dielectric constant and the scalar and tensor permeabilities are deduced from Q-factor measurements on the cavity. The methods are particularly suited to low-loss ferrites. 621.317.335.3 : 621.317.41 : 621.318.12

OBITUARY

WILLIAM THOMAS ANDERSON

William Thomas Anderson, who died on the 8th August 1957, was born in Manchester on the 3rd December 1869. He received his education at Manchester Grammar School prior to four years at King William's College in the Isle of Man.

He served a four-year engineering apprenticeship with John Hetherington and Sons, Manchester, and in 1893 joined F. H. Royce and Co., where, after a year's service, he was appointed an erecting engineer. In 1896 he joined J. M. Sumner and Co., and in their employment spent five years in Mexico on the installation and erection of electrical equipment.

Mr. Anderson began his long association with the electrical manufacturing industry in 1901 when he joined W. T. Glover and Co., Manchester. He served in many capacities with this company, with whom he remained until his retirement in 1941. He became a specialist in all matters respecting electricity in the mining industry and until his retirement managed the activities of the company associated with that industry. When electricity was first introduced to coal mining, he worked closely with the late Mr. J. A. B. Horsley, H.M. Chief Inspector of Mines, in the development of the regulations governing the use of electricity in mines.

During the 1914–18 War he was appointed by the Board of Trade to join an engineering trades mission to Spain. This led to a Government White Paper—in the preparation of which he played a leading part—on the 'Conditions and Prospects of the Iron, Steel and Engineering Trade.'

He was genial and lively in company, and he had in his personality a sort of engaging 'Pickwickian' impishness. His flair for photography covered an extensive field, and his skill in this connection was valuable in the investigation of the effects of explosions in mines.

Mr. Anderson joined The Institution as an Associate Member in 1903 and was elected a Member in 1912. He played an active part in the affairs of the North-Western Centre of The Institution from its early days.

He was a Council Member of the Manchester Geological and Mining Society, and a Member of The Institution of Mining Engineers. He was a Member of the Association of Mining Electrical and Mechanical Engineers which he joined in 1913, and was instrumental in the launching of the Association's journal. He became National President of the Association in 1923–4.

His loss will be deeply felt by his colleagues and many lifelong friends in the electrical engineering world. D. T. H.

ARCHIBALD BARR MACLEAN

Archibald Barr MacLean, M.A., B.SC.(ENG.), who was born on the 22nd March 1887, died at his home at Gosforth, Northumberland, on the 25th November 1957, after only a few years of retirement. He was educated at George Watson's College, Edinburgh, and Edinburgh University, where he obtained an M.A. degree in mathematics and natural philosophy. He then attended Glasgow University for eighteen months, gaining a B.Sc.(Eng.) degree, and had six months of practical training with Bruce Peebles and Co.

In 1912 he joined the British Thomson Houston Co., Rugby, as an Engineer in their Test Department and held various positions with the company until 1919, when he was appointed an assistant engineer with the Newcastle upon Tyne Electric Supply Co. In 1928 he left the company to become a partner of Messrs. W. C. Mountain, Son and Wood, consulting engineers, in which firm he remained for two years until he joined the Sunderland Corporation as Chief Assistant Engineer. This was followed by a year as a sales engineer with the Metropolitan-Vickers Electrical Co.

In 1932 MacLean rejoined the staff of the North-Eastern Electric Supply Co. (previously the Newcastle upon Tyne Electric Supply Co.) as a power sales engineer. He remained with the company until the electricity supply industry was nationalized in 1948, when he transferred to the North Eastern Electricity Board, and he was appointed Senior Assistant to the Head of the Mining Section, Chief Commercial Officer's Department.

Mr. MacLean, who was of a modest and retiring nature, was respected as a man of learning not only amongst his colleagues in the electrical world, but also by members of the coalmining industry in Northumberland and Durham. His favourite recreation was golf. He is survived by his widow.

Mr. MacLean joined The Institution as an Associate Member in 1919 and was elected a Member in 1927. He served as a member of the North-Eastern Centre Committee 1929–31. H. S.

RICHARD OLIVER WRIGHT

Richard Oliver Wright, who died on the 28th October 1957, was born on the 23rd October 1871. He was educated at Grosvenor College, Brixton, and began his electrical engineering education by studying part-time at Finsbury Technical College for two years. In 1886 he joined the Polytechnic School of Engineering, London, where he studied under Professor Spooner. In 1889 he became a pupil at the works of W. H. Allen and Co., Lambeth, and remained with the company for five years.

In 1894 he was appointed an engineer-draughtsman with James Simpson and Co., Pimlico, who specialized in the manufacture of pumping engines. Two years later he transferred to the Thames Iron Works and Shipbuilding Co., in order to widen his experience still further.

In 1898 he was appointed Assistant Works Manager with W. T. Henley's Telegraph Works Co., at a time when the manufacture of dry-core telephone cables was in its infancy, requiring the development of specialized machinery for its production. At that time Henley's built most of the machines they used, and these were generally of the wooden-framed type. Mr. Wright, in collaboration with the late Mr. R. Hatton, was responsible for the development of iron-framed machines, an innovation which was worthy of considerable comment at that time.

The rapid development of the demand for impregnated paper-insulated power cables necessitated a new factory site, and from 1904 onwards Mr. Wright planned, developed, and for thirty-one years managed, the company's Gravesend factory. In that time he saw the tyre factory and the research department open on the Gravesend site. It was a period of almost continuous expansion, during which the maximum transmission voltage required by the supply industry rose from 11 kV to 132 kV, and the size and weight of the cables produced rose proportionately. When the new works opened in 1906, the supply industry of the day did not require a cable drum heavier than three tons, and it is a tribute to Mr. Wright's far-sighted planning and judgment that his original concept still forms the basic pattern for the factory layout, despite the enormous changes which have occurred since. His early training and his natural flair for machine design were invaluable assets throughout his long association with Henley's; he retired from the company in 1937.

He was a quiet, kindly man, whose natural reserve tended to hide the strength of character that lay beneath, but those who knew him intimately remember him with genuine respect and affection. In the earlier years of his retirement his garden occupied much of his leisure time, but in the latter ten years his health prevented him from indulging in this hobby. He is survived by his widow, a daughter and two sons.

Mr. Wright joined The Institution as a Member in 1912.

W. H.

MONOGRAPHS AND PAPERS
published individually this month

Synopses of monographs and papers published individually before the next issue of the Journal are given below, and, unless otherwise stated, their dates of publication are this month. Reprints of all papers are available about two months after publication in the Proceedings. The prices shown below are post free. When ordering please quote serial number of paper or monograph. Books of 8 vouchers may be obtained from the Secretary, price 10s. each.

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[2] If a reprint of paper and discussion is also required a remittance of 1s. 3d. should be sent.

MONOGRAPHS

The Economic Loading of Transmission Systems
Monograph 294 S

H. NICHOLSON, M.ENG., *and* J. W. LYNN, M.SC.

In several publications Kron, Kirchmayer and others have outlined methods for transforming power-system operating data in terms of complex voltages and currents into information concerning real generator powers and transmission losses. These losses are related to the individual generator loadings by a set of constants which are dependent only upon operating conditions at normal load.

In the present paper Kron's methods for establishing a transmission-loss equation for a hypothetical 3-generator 2-load system are described and the analysis is extended for application to an actual section of the British network.

The coefficients of the loss equation are obtained from the basic impedance matrix of the system and various transformation matrices.

A method is developed for combining the loss formula with station fuel costs for economic system operation.

Tensor Analysis of Electrical Machine Hunting
Monograph 295 S

J. W. LYNN, M.SC.

The monograph gives first a brief résumé of previous work on tensor analysis of electrical machines. The steady-state equations of the synchronous machine are written with respect to Park's reference axes, and from these are derived the hunting equations. It is shown that these equations are part of a general group of transformations of reference axes of the synchronous machine, all of which are embraced by the general tensor equations. The hunting equations are then referred to a freely rotating system. These equations are rewritten in tensor form, and the significance of the grouping of terms into tensors is discussed. The author shows that the latter equations give a more realistic interpretation of the hunting equations and the equivalent circuit.

Intrinsic Directional Coupler using Elliptical Coupling Apertures
Monograph 296 R

J. FIGANIER, B.SC., *and* E. A. ASH, PH.D.

The use of elliptical coupling apertures between two rectangular parallel waveguides for the realization of intrinsic directional couplers is investigated. It is found that both codirectional and contradirectional characteristics can be obtained. The possibilities of using the intrinsic directional property to improve the characteristics of multi-element couplers or to construct filter couplers are examined.

Optimum Network Functions for the Sampling of Signals in Noise *Monograph* 297 R

H. S. HEAPS, B.SC., M.A., *and* M. R. MCKAY, B.E.

The paper examines the detection of a signal received upon a noise background, and determines the transfer functions of the networks which maximize (*a*) the ratio between the average amplitude of *n* successive samples of the output signal and the r.m.s. output noise and (*b*) a continuous sample of the output. The optimum ratio is calculated when the input is a rectangular pulse upon white noise or a cosine pulse upon non-white noise.

The Rate of Transmission of Information in Pulse-Code-Modulation Systems *Monograph* 298 R

A. R. BILLINGS, B.SC., PH.D.

A general expression is obtained for the maximum rate of communication of information in pulse code modulation systems using any scale of numbers, when the interfering noise has a Gaussian amplitude distribution. The particular cases of binary and tertiary coding are dealt with in more detail and a comparison is made between the communication rate R and the ideal channel capacity C. The author shows that for both systems the communication efficiency R/C reaches a maximum of the order of 80% at particular signal/noise ratios.

PAPER

Transistor Pulse Generators for Time-Division Multiplex
Paper 2577 R: *Part B*

K. W. CATTERMOLE, B.SC.

The author describes point-contact transistor circuits to generate pulses in the microsecond range together with means of frequency-dividing and interlacing pulse trains and their application to time-division operation of telephone transmission and switching systems.

To be read on the 19th March 1958

SOME RECENT BOOKS

A. KLINKENBERG and J. L. VAN DER MINNE (*Editors*)
ELECTROSTATICS IN THE PETROLEUM INDUSTRY

CLEAVER-HUME PRESS. 1957. 191 PP. 40S.

This is the most important work which has appeared on this particular aspect of electrostatics. Part 1 states the general problem which arises from the handling of petroleum products in bulk. It gives a general outline of the results of recent research and practical steps which may be taken to prevent explosion and fire hazards from this cause.

Part 2 gives an up-to-date study of several aspects of the generation of static charges by flow and gives a good account of recent theoretical and experimental work on this subject. It is by far the most comprehensive review of the subject so far brought together in one monograph. The theoretical treatment is based on the Helmholtz double layer, with a suggested correction for the conditions under turbulent flow, but the problem is complex and the last word has probably not been said on this matter. The section on the effect of anti-static additives is extremely interesting and the results are of considerable practical value.

Chapters are also included on the electric field in pipes and tanks and on spark ignition of inflammable vapours, and the chapter on large-scale field experiments is particularly valuable. A substantial difference between laboratory and field tests is reported, but fortunately the discrepancy is on the side of safety.

KENDALL BIRR
PIONEERING IN INDUSTRIAL RESEARCH: THE STORY OF THE GENERAL ELECTRIC RESEARCH LABORATORY

WASHINGTON: PUBLIC AFFAIRS PRESS. 1957. 204 PP. 36S.

This is an extremely readable account of the history and activities of one of the world's most famous industrial research laboratories. The laboratory was founded at the beginning of the century—within ten years of the formation of the General Electric Co.—and has been remarkably successful. The chief reason for this runs like a golden thread through the book—brilliant leadership. Whitney, Coolidge, Langmuir are the outstanding names, but there are many others almost equally well known. The sketches of the characteristics of these men throw much light on their methods of working. It is significant that great value was placed on informal internal collaboration and the need to collect a team of brilliant scientists without too much regard to their particular fields of knowledge. Such a policy would not have been possible without the whole-hearted collaboration of the company's management. The confidence of the management in the research laboratory never seems to have faltered; the laboratory's achievements to justify this are well described.

The book starts with a very useful chapter on the origin of industrial research in the United States and in Europe, but the remainder is devoted to the main theme. As might be expected, there is almost as much about the successful achievements of the General Electric Co. as about the laboratory itself; the two were interrelated and inter-dependent.

The laboratory's wide activities and claimed successes include oil immersion of X-ray tubes, gas-filled lamps, thyratrons, sodium lighting, ductile tungsten, moving-coil loudspeakers, magnetic pick-ups, thoriated filaments, Carbo-loy, balancing machines, hydrogen cooling of alternators and electric blankets. There are many other claims, though sometimes one is left with the impression that the General Electric laboratory alone was responsible for certain develop-ments, whereas in fact similar parallel, if not prior, develop-ments were proceeding elsewhere.

If there is one broad deduction which can be made, it is the impression that good-quality basic research in any field pays. Many of the laboratory's achievements were of use to the company, but many were profitable in other fields. Much research resulted in inventions, and interesting sidelights are given on American patent law, which, whilst basically a protective device making research worth while, was, on a short-term view, often a hindrance to development.

The whole story is fascinating and could be read with advantage by anyone interested in industrial research. It is not merely a list of successes but gives much insight into the prerequisites for success, the problems of converting a successful experiment into a saleable product, and other management functions associated with a central research department in an organization which has a large number of semi-independent works—many having their own laboratories.

H. COTTON
ELECTRICAL TECHNOLOGY

PITMAN. 1957. 865 PP. £2 10S.

The problems that have to be solved by an author in pre-paring any text for the use of students are always involved, and usually self-conflicting. The actual selection of the contents for the seventh edition of 'Applied Electricity' must have presented a difficult choice. When the first edition appeared, over thirty-two years ago, the selected material covered the requirements for the subject of electrical tech-nology in the final degree examination in engineering of the University of London. Since then the progress of technology has been so great that the contents of the original edition would now hardly suffice for the subject of applied electricity in Part I of the degree examination. The seventh edition, with the same general style and format, is a complete revision, and uses rationalized M.K.S. units, with considerable enlargement of almost all the thirty chapters.

The text, illustrated with 675 well-drawn line diagrams, is written for the benefit of students who are preparing for professional examinations of degree standard in electrical engineering. The author has included 257 problems for solution by conscientious readers, with answers provided to the numerical questions. There is also a selected set of 205 references for further reading.

In many respects the great length of the book is a dis-advantage. The size of the book is due to the attempt to cover the degree examination requirements in one volume. This is an almost impossible task since students only enter the degree course with physics at advanced level. In consequence

much essential material has had to be omitted, and the result is only an up-to-date presentation of traditional subject-matter appropriate to electrical machinery. In actuality over two-thirds of the text deals with electrical machines and plant, and much of the remainder covers the introductory technology essential for the understanding of electrical machine theory.

The text is so written that it is readily readable and the mathematics does not extend beyond linear differential equations. Most of the topics are emphasized by means of worked numerical examples, and in some the treatment goes beyond the level normally attained by such books. On the other hand the number of topics covered is so vast, reaching from the elementary to degree level, that much essential material is lacking.

The whole question of what should be included in textbooks for undergraduate work deserves thorough investigation. However readable the present book may be, the sheer size must create a psychological reaction in the first-year student. In any case he is probably already dismayed by the price, but in comparison with similar books this cannot be considered high.

LIBRARY ACCESSIONS

**Denotes that the publication is also in the Lending Library. The publications cannot be bought through The Institution; the publishers and the prices are given only for the convenience of members.*

BOOKS

ADMIRALTY 531.383

Manual of the Admiralty Gyro-Compass (Sperry Type) B.R.9 (53)

London, H.M.S.O., 1953. pp. x, 230. 28 × 15 cm. 25s.

A detailed description of the installation and adjustment of the compass and its associated electrical equipment. The book supersedes B.R.9 of 1941 and certain of the addenda thereto.

ALLARDICE, C. (Editor) 621.039

Atomic Power. An Appraisal including Atomic Energy in Economic Development*

London, Pergamon, 1957. pp. 151. 22 × 14 cm. 21s.

This book, which the layman will be able to understand easily, gives a clear simple explanation of the atom and the atomic nuclei, the way nuclear energy is released and controlled, the method of using radio isotopes in medicine and in industry, and the different techniques for using the heat generated for steam for electric power and for propulsion. The economics of the generation of electricity are dealt with in considerable detail.

AMERICAN INSTITUTE OF PHYSICS 53 (03)

American Institute of Physics Handbook

London, McGraw-Hill, 1957. pp. xi, 1,488. 23 × 15 cm. £5 12s. 6d.

This is a monumental work packed with definitions, nomenclature, physical constants and properties, formulae, and other useful data relating to the various branches of physics.

BRITISH INSULATED CALLENDER'S CABLES LIMITED 621.315.5

Electrical Conductors International Standard Sizes

London, British Insulated Callender's Cables Limited, 1957. pp. 84. 25 × 19 cm. 15s.

The tables show the nominal physical and electrical characteristics of the standard sizes of conductors included in British, American and Continental specifications.

BROWN, J. G. (Editor) 621.311.21

Hydro-Electric Engineering Practice

Vol. 1. Civil Engineering.* pp. xxvii, 1,189. £9 9s.

Vol. 2. Mechanical and Electrical Engineering.* pp. xxii, 740. £6 6s.

Vol. 3. Economics, Operation and Maintenance.* pp. xxiv, 473. £4 4s.

London, Blackie, 1958. 26 × 18 cm.

There are not many books on hydro-electric engineering, and the standard work on the subject was published eight years ago. This new comprehensive treatment of all aspects of the subject in three volumes is therefore most welcome. The book will be reviewed in a future issue.

BROWN, R. H., and LOVELL, A. C. B. 621.396.9 : 523.1

The Exploration of Space by Radio*

London, Chapman and Hall, 1957. pp. xii, 207. 25 × 16 cm. 35s.

A description of the results and possibilities of investigating the universe by radio methods and of the techniques and equipment used, including the Jodrell Bank radio telescope. The book will be reviewed in a future issue.

CANNING, R. G. 518.5

Installing Electronic Data Processing Systems*

London, Chapman and Hall, 1957. pp. xiii, 193. 23 × 15 cm. £2 8s.

This book, which is written in the main for management, deals with the period in which the detailed preparation for and installation of the equipment takes place. A hypothetical business is used as a means of illustrating the methods suggested.

DEWITT, D., and ROSSOFF, A. L. 621.314.7

Transistor Electronics*

London, McGraw-Hill, 1957. pp. xii, 381. 24 × 16 cm. £3.

A survey of semi-conductor physics is followed by a detailed consideration of the uses of transistors. Examples are given of the methods of calculating actual values for practical design purposes.

EDISON ELECTRIC INSTITUTE 621.315.23

Underground Systems Reference Book*

New York, Edison Electric Institute, 1957. pp. xxiii, 495. 29 × 21 cm. £5.

Originally published in 1931, this new edition has taken a staff of 134 three years to prepare. It is as comprehensive as possible and includes descriptions of all widely used practices for laying, maintenance, repair and testing in the U.S.A.

GUILLEMIN, E. A. 538.551

Synthesis of Passive Networks. Theory and Methods Appropriate to the Realization and Approximation Problems

London, Chapman and Hall, 1957. pp. xviii, 741. 23 × 15 cm. £6.

A logical, comprehensive approach to linear passive-network synthesis, in which a good knowledge of the necessary mathematics and of basic circuit analysis is assumed. A number of problems are solved by way of illustration, and there are others for the reader to solve.

Contents of the Current Issues of the *Proceedings*

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PART B. RADIO AND ELECTRONIC ENGINEERING (MARCH 1958)

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The Design of the Control Unit of an Electronic Digital Computer *January 1958*

M. A. MACLEAN, M.SC., AND D. ASPINALL, B.SC. PAPER NO. 2389 M
A Decimal Adder using a Stored Addition Table *January 1958*

T. KILBURN, M.A., PH.D., D.SC., G. R. HOFFMAN, PH.D., B.SC., AND R. E. HAYES, M.SC. PAPER NO. 2441 M
An Accurate Electroluminescent Graphical-Output Unit for a Digital Computer *January 1958*

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J. S. BELL. PAPER NO. 2464 R, MARCH 1958
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C. S. BULL, PH.D. PAPER NO. 2493 R, MARCH 1958
Space Charge as a Source of Flicker Effect *March 1958*

A. E. KARBOWIAK, PH.D., B.SC.(ENG.). PAPER NO. 2467 R, MARCH 1958
An Instrument for the Measurement of Surface Impedance at Microwave Frequencies *March 1958*

C. M. SRIVASTAVA, M.SC., PH.D., AND J. ROBERTS, B.SC.(ENG.). PAPER NO. 2518 R, MARCH 1958
Measurement of Ferrite Loss-Factors at 10 Gc/s *March 1958*

G. CRAVEN. PAPER NO. 2547 R, MARCH 1958
Wide-Band Waveguide Filters with Short Linear Tapers *March 1958*

PART C. MONOGRAPHS (MARCH 1958)

(*Reviews of monographs are not published in the Journal*)

A. E. KARBOWIAK, PH.D. NO. 246 R, JUNE 1957
The Concept of Heterogeneous Surface Impedance and its Application to Cylindrical Cavity Resonators

PROFESSOR G. W. CARTER, M.A., AND S. C. LOH, B.SC. NO. 247 M, JUNE 1957
The Approximate Calculation of the Electric Field between a Rod and a Concentric Ring by means of Toroidal Functions

J. S. SEELEY, PH.D., B.SC.(ENG.). NO. 248 R, JULY 1957
A Spectrometer Method for Measuring the Electrical Constants of Lossy Materials

T. J. LEWIS, M.SC., PH.D. NO. 249 M, JULY 1957
The Statistical Basis of Impulse Testing

P. H. G. ALLEN, B.SC.(ENG.). NO. 250 M, JULY 1957
The Thermal Properties of High-Voltage Insulants

H. GOLDENBERG, M.SC. NO. 251 S, JULY 1957
The Calculation of Cyclic Rating Factors and Emergency Loading for One or More Cables Laid Direct or in Ducts

J. W. HEAD, M.A., AND GWYNNETH M. OULTON, B.SC. NO. 252 L, AUGUST 1957
Coefficients for 'Decomposition' of Functions into Laguerre-Function Series

PROFESSOR J. C. JAEGER, M.A., D.SC., AND GORDON H. NEWSTEAD, M.E.E. NO. 253 S, AUGUST 1957
Transient Heating of Buried Cables

E. A. FREEMAN, B.SC. NO. 254 M, SEPTEMBER 1957
An Approximate Transient Analysis of a Second-Order Position-Control System when Backlash is Present

T. H. BARTON, PH.D., AND V. AHMAD, M.SC. NO. 255 U, SEPTEMBER 1957
The Measurement of Induction-Motor Stray Loss and its Effect on Performance

A. J. O. CRUICKSHANK, B.SC., PH.D. NO. 256 M, OCTOBER 1957
Generalized Operators for the Approximate Steady-State Analysis of Linear and Non-Linear Circuits

J. L. DOUCE, M.SC., PH.D. NO. 257 M, OCTOBER 1957
A Note on the Evaluation of the Response of a Non-Linear Element to Sinusoidal and Random Signals

LT.-CDR. J. C. G. FIELD, R.N., B.SC. NO. 258 R, OCTOBER 1957
The Design of Automatic-Gain-Control Systems for Auto-Tracking Radar Receivers

L. LEWIN. NO. 259 R, OCTOBER 1957
A Contribution to the Theory of Probes in Waveguides

C. S. JHA, B.SC. NO. 260 U, OCTOBER 1957
Some Tests on a Stator-Fed Polyphase Shunt Commutator Motor

BORIS G. KAZANSKY. NO. 261 R, OCTOBER 1957
Outline of a Theory of Non-Uniform Transmission Lines

B. B. JACOBSEN, B.SC.(ENG.). NO. 262 R, NOVEMBER 1957
Thermal Noise in Multi-Section Radio Links

W. T. J. ATKINS, B.SC.(ENG.). NO. 263 M, NOVEMBER 1957
An Improved Electromagnetic Analogue

K. FEARNSIDE, M.A., AND P. A. N. BRIGGS, B.A. NO. 264 M, NOVEMBER 1957
The Mathematical Theory of Vibratory Angular Tachometers

J. L. BROWN, JR., PH.D. NO. 265 R, NOVEMBER 1957
A Simplified Derivation of the Fourier Coefficients for Chebyshev Patterns

J. ALLISON, B.SC.(ENG.), PH.D. NO. 266 R, DECEMBER 1957
Variations of Characteristic Impedance Along Short Coaxial Cables

H. V. SHURMER, M.SC., PH.D. NO. 267 R, DECEMBER 1957
Transformation of the Smith Chart Through Lossless Junctions

G. H. METSON, M.C., PH.D., M.SC., B.SC.(ENG.). NO. 268 R, DECEMBER 1957
The Conductivity of Oxide Cathodes Part 3. Movements of Electrolytic Oxygen in a Conventional Diode System

G. H. METSON, M.C., PH.D., M.SC., B.SC.(ENG.). NO. 269 R, DECEMBER 1957
The Conductivity of Oxide Cathodes Part 4. Electron Transfer Mechanisms

PROFESSOR E. B. MOULLIN, M.A., SC.D. NO. 270 R, DECEMBER 1957
On the Amplification Factor of a Triode Valve: Part 2

W. DAVIES, PH.D., B.SC. NO. 271 U, DECEMBER 1957
The Sliding Contact of Graphite and Copper

R. I. B. COOPER, M.A., PH.D., AND J. RIDDLESTONE, B.A. NO. 272, DECEMBER 1957
The Variation with Current and Inductance of Metal Transfer between Contacts of Palladium and Silver

V. G. WELSBY, PH.D., B.SC.(ENG.). NO. 273 R, DECEMBER 1957
Electromagnetic Fields in a Ferromagnetic Medium, with particular reference to Harmonic Distortion due to Hysteresis

V. G. WELSBY, PH.D., B.SC.(ENG.). NO. 274 R, DECEMBER 1957
A Theoretical Investigation of the Form Assumed by a Submarine Cable during Laying or Recovery

G. G. GOURIET. NO. 275 R, DECEMBER 1957
Two Theorems Concerning Group Delay with Practical Application to Delay Correction

I. CEDERBAUM, PH.D. NO. 276 R, JANUARY 1958
Conditions for the Impedance and Admittance Matrices of *n*-Ports without Ideal Transformers

B. FRIEDMAN AND W. ELWYN WILLIAMS. NO. 277 R, JANUARY 1958
Excitation of Surface Waves

J. ZDUNEK, DIPL.ING. NO. 278 R, JANUARY 1958
The Network Synthesis on the Insertion-Loss Basis

G. D. MONTEATH, B.SC. NO. 279 R, JANUARY 1958
The Effect of the Ground Constants, and of an Earth System, on the Performance of a Vertical Medium-Wave Aerial

R. F. BURBIDGE, B.SC. NO. 280 S, JANUARY 1958
A Rapid Method of Analysing the M.M.F. Wave of a Single or Polyphase Winding

PROFESSOR ROBERT PLONSEY, PH.D. NO. 281 R, JANUARY 1958
Diffraction by Cylindrical Reflectors

Written discussion on **The Effect of Magnetic Saturation on the D.C. Dynamic Braking Characteristics of A.C. Motors**

PROFESSOR J. C. PRESCOTT, D.ENG., AND B. P. RAJU, M.SC. NO. 282 U, JANUARY 1958
The Inherent Instability of Induction Motors under Conditions of Double Supply

Written discussion on **The Measurement and Prediction of Induction Motor Stray Loss at Large Slips**

Forthcoming Events at Savoy Place

All meetings are held at Savoy Place, beginning at 5.30 p.m. (tea at 5 p.m.), except where otherwise stated. The nature of the meeting is indicated by the following key:

E EDUCATION DISCUSSION CIRCLE
I INFORMAL
M MEASUREMENT AND CONTROL SECTION
O ORDINARY
R RADIO AND TELECOMMUNICATION SECTION
S SUPPLY SECTION
U UTILIZATION SECTION

After each paper that has now been published is added the month that a synopsis has appeared in the *Journal* under 'Monographs and Papers published individually this month', i.e. about the time the paper has been published as a separate. A paper that has not yet been published will be available at least ten days before the meeting at which it will be read.

March 1958

R **19** *Wednesday* K. W. CATTERMOLE, B.SC. 'Efficiency and Reciprocity in Pulse-Amplitude Modulation. Part I—Principles' (Paper No. 2474 R) *Synopsis:* December 1957

J. C. PRICE, B.SC. 'Efficiency and Reciprocity in Pulse-Amplitude Modulation. Part II—Testing and Applications' (Paper No. 2475 R) *Synopsis:* December 1957

K. W. CATTERMOLE, B.SC. 'Transistor Pulse Generators for Time-Division Multiplex' (Paper No. 2577 R) *Synopsis:* see p. 155

O **20** *Thursday* R. L. BEURLE, PH.D., B.SC.(ENG.) Lecture on 'Storage and Manipulation of Information in the Brain'†

RM **21** *Friday* Joint Dinner-Dance (At the Café Royal, at 7 for 7.30 p.m.) (Particulars issued with the January *Journal*)

M **25** *Tuesday* L. ESSEN, D.SC., PH.D. Lecture on 'The Atomic Clock'†

S **26** *Wednesday* PROFESSOR F. GIORDANI Lecture on 'The Objective for Euratom'‡

R **27–28** *Thursday–Friday* Convention on 'Radio Aids to Aeronautical and Marine Navigation' (Full details and registration form obtainable from the Secretary)

R **31** *Monday* Informal Evening on 'Future Radio-communication Methods for Civil Aircraft', at which there will be a talk given by W. E. BRUNT†

April

E **1** *Tuesday* D. J. BOLTON, M.SC.(ENG.), will open a discussion on 'Economic Aspects of Electrical Engineering'* (At 6 p.m., tea at 5.30 p.m.)

R **9** *Wednesday* Informal Evening on 'U.H.F. Test Transmissions'

O **10** *Thursday* J. A. RATCLIFFE, O.B.E., M.A., F.R.S. Lecture on 'Radio Observations on Artificial Satellites'‡

I **14** *Monday* FORBES JACKSON will open a discussion on 'The Future Trend of Installation Inspection'*

MU **15** *Tuesday* PROFESSOR E. BRADSHAW, M.B.E., M.SC.TECH., PH.D., M. WAGSTAFF, M.SC.TECH., *and* F. COOKE 'A Train Performance Computer' (Paper No. 2425 M) *Synopsis:* November 1957

J. F. MEREDITH, B.SC., *and* E. A. FREEMAN, B.SC. 'The Simulation of Distributed-Parameter Systems, with particular reference to Process Control Problems' (Paper No. 2376 M) *Synopsis:* July 1957

J. L. DOUCE, M.SC., PH.D., *and* J. C. WEST, PH.D., B.SC. 'A Magnetic-Drum Store for Analogue Computing' (Paper No. 2393 M) *Synopsis:* July 1957

* No advance information will be available and no Press report will be permitted.
† An abstract will be available in advance.
‡ No advance information will be available.

Forthcoming Events at Savoy Place (*contd.*)

April

S **16** *Wednesday* (In conjunction with the British Nuclear Energy Conference) K. L. STRETCH, M.A. 'Operational Experience at Calder Hall' (Paper No. 2594 s)

U **17** *Thursday* R. F. BURBIDGE, B.SC. '2/1 Pole-Changing Motors'‡

R. S. WIGNALL, B.SC. 'Project Considerations for Diesel Electric Traction'‡

A. WREN 'Some Applications of Mercury-Arc Rectifiers'‡

R **23** *Wednesday* D. E. L. SHORTER, B.SC.(ENG.) 'Survey of Performance Criteria and Design Considerations in High-Quality Monitoring Loudspeakers' (Paper No. 2604 R)

O **24** *Thursday* H. V. PUGH 'The Generation of Electricity in the London Area' (Paper No. 2445 s) *Synopsis:* November 1957

R **28** *Monday* Informal Evening on 'Economic Usage of Broad-Band Transmission Systems' at which there will be a talk given by R. J. HALSEY, C.M.G., B.SC.(ENG.)†

MS **29** *Tuesday* J. N. PREWETT, M.A. 'A Method of Measuring and Displaying Generator Rotor Angle' (Paper No. 2602 M)

E. B. POWELL *and* M. E. HARPER 'Generator Rotor-Angle Measurement by Stroboscopic Means' (Paper No. 2576 M)

F. MORAN, M.SC. 'Power-System Phase-Angle Measurements' (Paper No. 2583 s)

S **30** *Wednesday* F. C. WINFIELD, M.ENG., T. W. WILCOX *and* G. LYON, M.SC.(ENG.) 'The Design of the 330 kV Transmission System for Rhodesia' (Paper No. 2583 s)

May

M **6** *Tuesday* A. T. STARR, M.A., PH.D., B.SC. Lecture on 'Some Case Histories of Business Computers in the U.S.A.'‡

U **8** *Thursday* P. T. STANDRING, PH.D., B.SC. Lecture on 'Artificial Fibres'‡

E **9** *Friday* G. MATHER, B.SC.TECH., will open a discussion on 'The Teaching of Applied Acoustics'* (At 6 p.m., tea at 5.30 p.m.)

R **14** *Wednesday* D. GABOR, DR.ING., F.R.S., P. R. STUART *and* P. G. KALMAN 'A New Cathode-Ray Tube for Monochrome and Colour Television'

15 *Thursday* ANNUAL GENERAL MEETING *followed by* D. G. FINK Lecture on 'Recent Developments in Electronics in the United States'‡ (At approximately 6.30 p.m.)

U **16–18** *Friday–Sunday* Section Visit to Porthcawl

* No advance information will be available and no Press report will be permitted.
† An abstract will be available in advance.
‡ No advance information will be available.

May

R **19–23** *Monday–Friday* International Convention on 'Microwave Valves' (Full details and registration form obtainable from the Secretary)

An announcement about a District Meeting appears on p. 165.

British Nuclear Energy Conference: Forthcoming Programme

Details of three forthcoming meetings of the British Nuclear Energy Conference are given below. They will be held at 5.30 p.m., with tea at 5 p.m.; tickets of admission are not required.

1958

MARCH 18 *Tuesday*

Sponsoring society and place of meeting: The Institution of Civil Engineers, Great George Street, London, S.W.1.

James Forrest Lecture on FURTHER DEVELOPMENTS IN NUCLEAR POWER

Sir John Cockcroft, O.M., K.C.B., C.B.E., F.R.S.

APRIL 16 *Wednesday*

Sponsoring society and place of meeting: The Institution of Electrical Engineers, Savoy Place, London, W.C.2.

OPERATIONAL EXPERIENCE AT CALDER HALL

K. L. Stretch, M.A.

Advance copies will be available not later than ten days before the meeting from the Secretary of The Institution of Electrical Engineers.

MAY 1 *Thursday*

Sponsoring society: The Institute of Metals.
Place of meeting: Church House, Westminster, London, S.W.1, at 2.30 p.m.

SYMPOSIUM ON PLUTONIUM AND METHODS OF HANDLING IT

A HISTORY OF THE EARLY BRITISH WORK ON PLUTONIUM METALLURGY

Professor J. G. Ball and W. B. H. Lord

SOME FACILITIES FOR THE STUDY OF PLUTONIUM AND ITS ALLOYS

G. K. Williamson, D. M. Poole and J. A. C. Marples

TECHNIQUES FOR THE STUDY OF PLUTONIUM METAL

W. B. H. Lord and M. B. Waldron

THE PLUTONIUM-IRON SYSTEM

P. G. Mardon, H. R. Haines, J. H. Pearce and M. B. Waldron

A PRELIMINARY INVESTIGATION OF THE PLUTONIUM-THORIUM SYSTEM

D. M. Poole, G. K. Williamson and J. A. C. Marples

SOME INVESTIGATIONS ON PLUTONIUM METAL

E. Dempsey and A. E. Kay

All six papers will be printed in *The Journal of the Institute of Metals* before the date of the symposium.

ANNOUNCEMENTS TO MEMBERS

THE HOMES FUND

SUMMARY OF CONTRIBUTIONS RECEIVED TO 21ST FEBRUARY 1958

	No. of Contributors	£	*s.*	*d.*
£1 000 and over	6	6 000	0	0
£100 to <£1 000	30	6 586	3	0
£5 to <£100	851	9 041	16	7
£2 to <£5	2 049	5 591	2	11
Under £2	23 445	12 189	0	3
		£39 408	2	9

APPOINTMENTS AND NOMINATIONS

NEW SOUTH WALES OVERSEA COMMITTEE

The Council have appointed Mr. D. K. Muir, ASSOCIATE MEMBER, as Honorary Secretary of the above Committee in succession to Mr. J. T. Rollo.

BRITISH NATIONAL COMMITTEE FOR NON-DESTRUCTIVE TESTING

The Council have nominated Mr. C. G. Garton, MEMBER, to serve as their representative on the above Committee.

EXECUTIVE COUNCIL OF THE NATIONAL SOCIETY FOR CLEAN AIR

The Council have nominated Mr. C. T. Melling, C.B.E., M.SC.TECH., MEMBER, to serve as their representative on the above Council.

WIRING REGULATIONS—INTERPRETATIONS

Following the publication in September 1956 of the first abstract of interpretations of the 13th Edition of the Regulations, arrangements were made to release further abstracts at regular (probably quarterly) intervals; the most recent was published in September 1957. No matters of general interest having been raised since that time, no abstract was issued in December 1957 and none will be issued in March 1958. The question of further publication will be reviewed in time for a June 1958 issue, should this be required.

The abstracts which have so far been published are listed below, and reprints are obtainable from The Institution, price 6d. each, including postage.

The abstracts of interpretations of Regulations in the 12th Edition, being no longer relevant, are not separately available.

	Interpretations	*Date of Issue*	*Reference to publication in the Journal*	*Regulations Nos.*
1.	1–22	3.9.56	1956, 2 (New Series), October, p. 598.	108, 112(B), 114(B), 115, 203, 204(B), 206(A), 207(G), 209(F), 229(B), 307(A), 314, 315, 316, 401, 403, 404, 405(B), 603(A). Section 8. Tables: C, 1, 7, 16–22.
2.	23–27	3.12.56	1957, 3 (New Series), January, p. 31.	114(B)(ii), 214(B), 322, 403, 404, 405(D).
3.	28–31	1.3.57	1957, 3 (New Series), March, p. 154.	407(iv), 503. Tables: 12–24, 26.
4.	32–41	2.9.57	1957, 3 (New Series), September, p. 496.	General, 110, 115, 208(D), 218, 229, 311, 314, 315, 404, 405(C), 606(i).

RADIO OBSERVATIONS ON THE RUSSIAN SATELLITES

At a meeting of the Radio and Telecommunication Section on the 22nd November, 1957, a number of short contributions were presented, describing the part played by radio in observing the behaviour of the Russian earth satellites. There were two sessions, at each of which the contributions were followed by a discussion. At the end of the second session there was a general summing-up by Dr. R. L. Smith-Rose.

A report of the meeting (about 35 pages) is being published this month in Part B of the *Proceedings*. Reprints of the report, price 2s. 6d. (post free), will be available in about six weeks' time.

SUPPLY SECTION

VISIT TO LEATHERHEAD: 31ST MAY 1958

Arrangements have been made for a visit of members of the Supply Section and their ladies to Leatherhead on Saturday, 31st May 1958.

The programme will include visits for the members to the Electrical Research Association Laboratory, and for the ladies to the Electrical Development Association Testing House. The whole party will go to Polesden Lacey in the afternoon. Full details and application forms are enclosed with this issue to all members of the Section.

VISIT TO EDINBURGH: 18TH–21ST SEPTEMBER 1958

At the kind invitation of the Scottish Centre Committee, the Supply Section will visit Edinburgh from Thursday 18th September to Sunday 21st September 1958. Preliminary details and application forms were enclosed with the February issue to all members of the Section. In addition to those firms mentioned in the circular, a visit is also being arranged to the Telegraph Condenser Co., of Bathgate.

STUDENTS' QUARTERLY JOURNAL

The March issue of the *Students' Quarterly Journal*, in addition to papers on coal winding electrically, audio-frequency telephone cables, traffic control, motor circuit control and submarine cables, will have the text of a special paper read to the London Section last November on 'The Tracking of the Russian Earth Satellite'. Section notes and book reviews complete the issue.

1958 NUCLEAR CONGRESS AT CHICAGO

The tentative programme for the 1958 Nuclear Congress, which is being held in Chicago from the 17th to 21st March 1958, has now been drawn up. The Congress is sponsored by the American Nuclear Society and some thirty other American engineering and scientific societies, and it is co-ordinated by the Engineers' Joint Council. There will be thirty-seven sessions, covering many aspects of nuclear research and development. Preprints of papers, priced at 50 cents each, are now available from the Congress Manager, American Institute of Chemical Engineers, 25 West 45 Street, New York 36, N.Y., from whom a list of the papers so far accepted can be obtained.

BRITISH ELECTRICAL POWER CONVENTION

BRIGHTON: 16TH–20TH JUNE 1958

'Electricity and World Progress: Britain's Contribution' will be the theme of the tenth British Electrical Power Convention, to be held at Brighton from the 16th to 20th June 1958, under the presidency of Sir George Nelson. An electrical exhibition, run in conjunction with the Convention, will be opened by Sir George on the evening of the 16th June. The first session of the Convention will be held in the Dome the following morning, when, after a civic welcome by the Mayor of Brighton, Sir George will give his presidential address. In the afternoon Sir Christopher Hinton will read a paper on 'The Development of Nuclear Energy for Electricity Supply in Great Britain'. This theme will be continued the next day with an address by Sir Claude Gibb on 'The Development of Nuclear Energy for Electricity Supply Overseas'. Succeeding papers will deal with British electrical development abroad, hydro-electric plant and domestic electrical equipment. On Thursday evening, the 19th June, the Annual Dinner and Dance will be held at the Corn Exchange, and after the popular Electrical Forum the next morning, the Convention will conclude with the Annual General Meeting.

Members may obtain further information from the Secretary, British Electrical Power Convention, Eastcastle Street, London, W.1.

INTERNATIONAL CONVENTION ON TRANSISTORS

The Radio and Telecommunication Section, with the approval of the Council, is arranging an International Convention on Transistors and Associated Semi-conductor Devices, which will be held during the period 25th–29th May **1959**. Further details will be announced shortly.

A STAFF VACANCY

The Institution will shortly have a vacancy in a senior post on the editorial staff and invites inquiries. Applicants must be qualified engineers or scientists with some knowledge of typography and layout, and able to write special articles and to rewrite, condense or expand other material. Journalistic experience would be an advantage. The commencing salary would be according to qualifications and experience. Entry to a superannuation scheme would follow a short period of service.

Those who are interested should write to the Secretary at Savoy Place, London, W.C.2, giving full particulars of their education, training and experience.

A NEW BRITISH STANDARD

Copies of the following publication can be obtained from the British Standards Institution, 2 Park Street, London, W.1. The price is post free.

B.S. 2929: 1957 **Safety Colours for Use in Industry** 4s. 6D.

This Standard is a new attack on industrial accidents. Its purpose is to establish throughout industry the use of a universal system of colours for the identification of hazards and safety equipment.

As these recommendations are applied in factories, mines, shunting yards and other industrial installations, the confusion which now exists through the use of a variety of different colour codes should gradually be removed. The main advantage will be to associate in the minds of work-people certain colours and signs with particular types of hazard, an association of ideas which will not be upset should workers move to a different department in the same works or to a completely different factory or site. Indeed, the new system is in substantial agreement with the code of safety colours shortly to be recommended for world-wide adoption by the International Organization for Standardization. This international code, when adopted, should help to safeguard workers moving from one country to another by establishing a universal and easily-recognized safety-colour system.

The new recommendations are extremely simple. The colours are: red, orange-yellow and green.

Red has the meaning 'stop'

Orange-yellow means 'warning of danger'

Green is used to identify or locate safety equipment and safety routes.

Contrasting colours are used with the three main colours to form patterns which make for easier visibility. Thus a red and white chequered pattern would be used for the door of a store containing petroleum spirit.

Geometrical forms, associated with definite colours, may be used as part of a safety message, and will have the meanings:

Circle	an order	red
Triangle	caution	orange-yellow
Rectangle	safety information	green

This scheme is important, because colours lose their value in some kinds of artificial light, and are in any event useless to colour-blind people.

The following are examples of the application of the standard safety colours:

Red for buttons, handles or wires to be used in an emergency to stop a machine; also for fire-fighting equipment.

Red and white chequered pattern to indicate barricades and obstructions.

Orange-yellow with black diagonal stripes to give warning of risks arising from changes in floor level, floor and head obstructions and open machinery guards.

Green for fire and emergency exits (except for lettering, which is red).

A green cross, in place of the familiar red one, is recommended for use on first-aid cabinets and so forth. This break with tradition was agreed on by the Committee which drafted the Standard, for these reasons: the green cross symbol is in line with the international code referred to above; and green is already clearly associated in the public mind with safety, while red carries the meaning 'stop—keep away!'

The Standard has the essential qualities of simplicity and unity, and thus represents a welcome advance on existing methods. There is, however, a regrettable inconsistency in the use of patterns and colours.

An example of this is the use of the pattern of red and white squares on the door of a petroleum store, since rectangular shapes (of which the square is a particular instance) are intended to be associated with safety, as is the colour green. It would have been more logical to use a pattern of red circles on a white background. The same criticism applies to the sign for an obstruction on a railway line, while the sign denoting an eyewash bottle should preferably have been surrounded by a green rectangle, to distinguish it in artificial light from a bottle of dangerous chemical.

JOINT MEETINGS

On the 12th December a joint meeting of the Radio and Telecommunication Section and the Utilization Section was held under the Chairmanship of Mr. J. Vaughan Harries, at which an interesting paper *Electric Control of Stage and Television Lighting* was read by F. P. Bentham. The paper is reviewed on p. 139. The author surveyed the progress made in these fields during the past twenty-five years and described the various types of dimmer and their uses, with particular reference to remote control. He said that he had always disliked a 'switchboard approach' to lighting control and preferred to regard the switchboard as a kind of organ console, which, although in reality only a complex switchboard, is to the organist an artistic instrument. Accordingly, the modification in 1935 of the organ-console form of control to suit lighting was a natural step to take, but this system, known as the *light console*, was not really accepted until ten years ago. Finally, the author stressed the important point that television or theatre production is not a mechanical, but a human, affair with human advantages and human failings. Consequently it does not lend itself to the application of automation, because last-minute changes due to inspiration or accident occur at any time, even during transmission or performance. In these circumstances, controls requiring premeditated setting up are not flexible enough, whereas the emphasis in such conditions is to expect a quick appraisal and the ability to conform or remedy.

The ensuing discussion was opened by Mr. K. R. Ackerman, of the B.B.C., who pointed out the essential difference between the control of light for the theatre and for television. In the former he said the electrician-operator repeated predetermined lighting arrangements night after night, whereas in the latter the lighting supervisor 'painted his picture' according to the needs of the moment, aided by a monitoring screen. He also expressed the opinion that an attempt should be made to achieve some degree of standardization of layout and operation.

It was encouraging to learn from one speaker that the developments described in the paper in controlling television lighting are considerably in advance of anything at present available on the Continent.

Mr. L. G. Applebee traced, in a most interesting way, from his own experience, the development of stage lighting from before 1914, and said that, in his opinion, the siting of the control board should be in the auditorium itself, so that the operator was able to see everything. The view was expressed that among the attributes of the operator of a lighting console for television should be that of considerable artistic appreciation.

On the other hand a suggestion was put forward that computers and punched cards should be used for the whole operation and that eventually the control might be effected by pre-recorded tape. Our old friend, Mr. P. P. Eckersley, even asked the author whether his lighting was really necessary. He also made reference to the temptation of television to 'fidget' with such an infinite variety of equipment, and, in this connection, he said that he did not like to look at an orchestra as if he had been transported underneath the harpist's foot! Mention was made by another speaker of the necessity for adequate training of lighting supervisors if they were to become efficient operators, and he suggested that a more appropriate description of them might be 'lighting engineer-artists'.

Mr. Bentham, in his reply to the discussion, referred to the facts that lighting in show business was like drains—not exciting but nevertheless very necessary—and that producers, as a race, are most impatient men.

The Chairman of the Radio Section, Dr. J. S. McPetrie, who also took part in the discussion, supported Mr. Vaughan Harries in the vote of thanks which the latter proposed to the author.

R. H. R.

Eliminating the Variables

When a research worker plans a set of experiments he must always endeavour to eliminate as many of the variables as possible, so as to concentrate on the particular phenomenon he is investigating. An odd result of this was illustrated at the joint meeting of the Measurement and Control Section and the Supply Section held on the 7th January 1958, when it became apparent that, although the title of the paper was *The Breakdown of Transformer Oil Under Impulse Voltages*, transformer engineers contributing to the discussion considered the substance investigated by the authors to be so refined as scarcely to be properly described as transformer oil. The paper is reviewed on p. 141.

The authors were Dr. R. Hancox and Dr. H. Tropper, who were describing work they had carried out at Queen Mary College, London. In introducing the paper, Dr. Hancox reviewed the present methods of testing and explained that the work carried out by different investigators was very difficult to correlate. The work he and his colleague had undertaken was intended to study the impulse breakdown of larger samples of oil with higher breakdown voltages and to investigate the relevance of such tests to industrial requirements. They were also concerned to ascertain the effects of pretreatment of the oil and the dependence of the measured breakdown strength on the test procedure adopted and on the electrodes used.

They confirmed the 'conditioning effect' observed by other workers and believed that this effect, which leads to an increase in strength with successive breakdowns, provided a clue to the breakdown mechanism. During tests, initial breakdowns were found to result in a single isolated pit on each electrode, but after the conditioning was complete further breakdowns tended to be erratic and multiple craters were formed on the cathode. It appeared that breakdown was being initiated at these points. The authors considered that these irregular crevices led to the formation of gas bubbles and that the disturbance of the field and increase in electron emission so caused led to the results they had obtained. This was confirmed by the fact that, while degassed oil exhibited a conditioning effect, ordinary oil did not.

The discussion was opened by Dr. J. B. Higham, who had carried out similar work at Birmingham University, but with different results. He said that the conditioning effect occurred in his experiments whether the oil was degassed or not. He felt that a rewarding next step in the investigation would be

to probe the differences between his results and those of the authors.

It was Mr. E. T. Norris who introduced a jarring note by saying that there appeared to be no resemblance between the substance the authors called transformer oil and the substance generally found in transformers and circuit-breakers. He said that chemically pure oil could give an electric strength of 10^6 volts/in., and the authors were not really measuring the electric strength of transformer oil but only that of the impurities in it.

Mr. C. T. Garton did not agree entirely with the authors' bubble theory, and put forward the alternative idea that water adsorbed on the electrode surfaces would break up under the influence of the field, so that the hydrogen ions would stay on the electrode and the hydroxyl ions would migrate into the oil. The hydrogen ions would then increase the emission. Several other speakers discussed the bubble effect, and Mr. R. E. Wootton showed some slides of bubble formation within an actual test cell, so that the meeting began to resemble the advertisements of a well-known mineral-water manufacturer.

Mr. J. K. Webb rounded off the discussion by considering the paper to be academic in its relation to engineering practice: Both Dr. Hancox and Dr. Tropper replied and acknowledged that it was due (in large measure) to Mr. Garton's encouragement that the paper was prepared. They felt that perhaps in the paper they had fallen between two camps, namely the engineers and the physicists, and they trusted that they had not become the enemies of both.

A vote of thanks to the authors was proposed by Mr. J. E. L. Robinson, a Vice-Chairman of the Supply Section, who brought to an end a well-attended and controversial meeting in characteristic style. E. W. C.

ORDINARY MEETING

The Bedford Story

The story of the Bedford wind tunnel was told at an Ordinary Meeting of The Institution on the 9th January 1958, with the President in the chair.

Four papers were presented: *The Development of Variable-Speed High-Power Drives for Large Wind Tunnels* and *A Variable-Frequency Power Installation for Large Wind-Tunnel Drives*, by P. McKearney, L. S. Drake and E. G. Mallalieu; *Speed Control of Large Wind Tunnels with particular reference to the R.A.E. 8 ft × 8 ft High-Speed Wind Tunnel*, by L. S. Drake, J. H. Fox and G. H. A. Gunnell; and *Automatic Setting of the Flexible Walls of a Large Wind Tunnel*, by T. Barnes and C. R. Dunham. The papers are reviewed on pp. 143–149.

To overcome the difficulties of presentation by so many authors, Mr. P. McKearney summarized the papers in a 35-minute talk illustrated by lantern slides and a short film. He covered very briefly the early history of wind tunnels, from the first one designed by Prandtl in 1910 to the giant 8 ft × 8 ft tunnel at Bedford, with its 810 ft path of travel of the air, its mass flow of 1 800 lb of air per second, and its 200 miles of $1\frac{1}{2}$-in. tube in the cooler.

Mr. McKearney emphasized the accuracy of the speed control of the air compressors, an error of only 0·1% being permissible.

The discussion was opened by Mr. P. T. Fletcher, who made the point that some of the wind tunnel's sophisticated refinements may have application in the design of nuclear power stations, the cooling-gas circuits of which were not dissimilar. He also mentioned that the position in other countries—particularly the United States—in regard to wind tunnels had been carefully studied in the early design stages of the Bedford tunnel.

Mr. F. M. Scholes dealt largely with the control gear. He asked himself whether the control could have been accomplished in any other way; in other words, if a second tunnel had to be built, would one use the same methods to achieve the desired end? The answer, of course, is that no two schemes of this magnitude would ever be exact duplicates, there would always be improvements embodied in the second. But Mr. Scholes felt that the same basic concept would be chosen, namely control by means of punched or magnetic tape.

The accuracy of voltage control was the subject of some discussion, and this led to talk on the speed control of the driving motors. Mr. J. J. Thomson criticized the use of a complicated system of a.c. and d.c. motors and suggested that plain turbine drive, with Velox boilers supplying the steam, could give just as precise a control of speed as the present arrangement. This statement was refuted by one of the authors, who reminded the meeting that the purpose of the tunnel was solely that of research on aerodynamics, not on speed-control—a riposte which elicited some amusement. Further, the employment of steam-turbine drive would increase the standby losses—an important point in the economics of wind-tunnel administration.

There were nine speakers in all, and four of the authors replied to the questions.

The Chairman of the Utilization Section, Mr. J. Vaughan Harries, proposed a vote of thanks to the authors.

Finally, as an addendum to the technical discussion, one of the speakers raised the question of the method of presentation of papers such as these, which describe a very large project. A complete description of the Bedford tunnel was only to be found in papers before the three major engineering Institutions, as mentioned in the bibliographies. Further, any effort to combine all of these papers under one cover was impossible owing to difficulties of format. Thus, anyone from abroad wishing to have the complete story was faced with the trouble of writing to several organizations. The speaker thought that there should be standardization of format between the three Institutions. Moreover, in a project as large, as new, and as sophisticated as this, a joint session or a symposium would seem to be the best way of accomplishing the desired end.

UTILIZATION SECTION

Polish Railways

At the meeting of the Utilization Section on the 24th October 1957, Mr. J. Podoski delivered a lecture on *The Post-War Electrification of the Polish State Railways*, in which the progress and future plans of the scheme were outlined. The lecturer pointed out that the Polish railway system not only played an important part in the economic life of the country but also carried a much larger proportion of the freight and passenger traffic than did British Railways. He also made reference to the participation of British firms in the original electrification scheme, which was successfully completed a year or so before the outbreak of the Second World War. In view of the decision to adopt a single-phase 50 c/s supply in Great Britain, it was interesting to learn that consideration

had been given to its use in Poland, but, since the advantages of this could not be realized under Polish conditions at the present stage of development, the conclusion was reached that the electrification should be continued at 3 000 volts d.c., although the application of the a.c. system was not entirely ruled out in the future. Mr. Podoski gave estimates of the amount of electrical equipment which would be required for the whole scheme and the anticipated saving in coal; it is expected that the economies in fuel alone will cover the total cost of electrification in about eight years.

In opening the discussion, Mr. B. Rabbetts suggested that with socialism and centralization, the Polish engineers had been in a position of working without considering the cost, to which the lecturer replied that under socialism, capitalism or 'any-ism', cost was extremely important, and they were in fact paying now in Poland for not having worried about cost at the beginning.

Among the various other points which emerged from the discussion were the reasons for two contact wires being used in Poland. These were said to be less trouble when the pantograph was taking a large heating current during cold weather while the train was stationary. Also, the reduction in voltage drop, which enabled substations to be located farther apart, effected considerable financial savings. It was somewhat surprising to hear from Mr. Podoski that frost is a greater problem than snow, which is handled by snow-ploughs.

The Merits of Convertors

A paper entitled *D.C. Winder Drives Using Mercury-Arc Rectifier/Inverters* was read at the meeting on the 14th November by L. Abram, J. B. McBreen and J. Sherlock. It is reviewed on p. 149. The paper compared a.c. and Ward Leonard drives with a rectifier drive for winders, and, on account of the efforts which are continually being made to reduce hoisting costs, the rectifier drive appears to be desirable owing to its high efficiency. The authors gave details of such an equipment provided at Monk Bretton colliery, and described the comprehensive series of tests which had been carried out on this installation.

Mr. B. L. Metcalf, opening the discussion, referred to comparative costs of the various methods of drive and remarked on the poor power factor of the rectifier drive at starting; this increased the reactive power drawn from the line and thereby made regulation worse than with the Ward Leonard and a.c. systems, thus probably adding to the cost of the supply lines. On the other hand he said there might be some gain in respect of the housing required for a rectifier compared with that necessary for the motor generator of a Ward Leonard winder.

Mr. J. E. Boul drew attention to the fact that, although suitable mercury-arc rectifiers for reversing drives had been available in this country for many years, their application had been delayed owing to the fear of complexity and measure of conservatism which hitherto existed, and he also pointed out that, as regards terminology, the use of the term 'convertor' was recommended by the International Electrotechnical Commission, since the so-called rectifier had nowadays to serve the dual purpose of rectification and inversion. Among the other comments made was that the paper marked another stage in the successful application of the mercury-arc rectifier and was an example of the increasing confidence in its use for all kinds of applications. The view was also expressed that the battle between the a.c. and d.c. protagonists now seemed to have given place to a new conflict involving field reversal versus armature reversal. R. H. R.

RADIO AND TELECOMMUNICATION SECTION

At the lecture on the 22nd January by Dr. E. Esping on *Special Problems of Broadcasting in Sweden* there was an audience which included an unusually high percentage of very senior engineers, many of whom knew from previous experience that Dr. Esping's address would be both enjoyable and instructive. The occasion was also marked by the presence of the Swedish Ambassador.

Dr. Esping set out the background of broadcasting in Sweden—a keen public with the greatest percentage of broadcast licences in Europe, the low population density, the very large country to be covered, and the problem which it shares with the rest of Europe of the few available long- and medium-wave channels. Some years ago a committee appointed by the Government had decided that v.h.f./f.m. transmission did not give a complete solution to Sweden's broadcasting problems, and it recommended a carrier method of distributing broadcast programmes on the long-wave band over the Post Office telephone network. This type of wired wireless enables the consumer to use a standard broadcast receiver. Two factors contribute to the success of this method in Sweden, namely the many telephone subscribers and the broadcasting and telephone services being under the same administration. The unusual feature of the wired-wireless system is that it has been introduced to cover the country districts. Naturally the use of frequency modulation figures in the general plan, and fourteen of the twenty-one projected f.m. stations are now in operation. These transmitters are designed for unattended operation, which is in line with the present policy for all transmitters.

On the engineering side, Dr. Esping gave an interesting account of a new transmitter built underground four kilometres east of Stockholm. That certainly brings cave dwelling up to date with a vengeance! Another interesting development mentioned is the plan for an anti-fading aerial to be installed at the Motala transmitter. This will be a ring-aerial system with a centre mast 250 m high and five ring masts of 200 m height at a radius of 625 m. Tests have indicated that from a subjective point of view the high Q-factor of the aerial system will not introduce serious distortion.

Sir Noel Ashbridge opened the discussion by referring to the way Sweden had made the best possible use of available broadcasting techniques. He also paid tribute to the excellent work which Dr. Esping had done towards international collaboration, in particular his work for the C.C.I.R. The emphasis on wired wireless in the Swedish plan enabled one of our distinguished and regular contributors—you can guess his name—to be both witty and relevant. The interesting fact that wired wireless was used for country districts and frequency modulation for the more densely populated areas was discussed by Sir Harold Bishop. Sir Harold commented too on television developments in Sweden, and, with the knowledge that he spoke for all those present, added his congratulations to Dr. Esping for coping so brilliantly with the lecture and the questions in a foreign language. A. J. B.

A District Meeting

March 1958

HATFIELD (At Hatfield Technical College, Roe Green, at 7 p.m., tea at 6.15 p.m.)

27 *Thursday* A. DOUGLAS 'Electrical Synthesis of Music'

NEWS *from the Centres*

EAST ANGLIAN SUB-CENTRE

The President and the Secretary of The Institution were guests at the second Annual Dinner-Dance of the East Anglian Sub-Centre held at the Dorothy Restaurant, Cambridge, on the 3rd January 1958.

The Sub-Centre Chairman, Mr. G. E. Middleton, the President and their ladies, received members and their guests at 7.0 p.m., and dinner was served at 7.30 p.m. at small tables around the ballroom. After dinner the Chairman welcomed the other official guests including the Mayor and Mayoress of Cambridge, officials of the Eastern Branch Committee of The Institution of Mechanical Engineers and the Chairman and Hon. Secretary of the East Midland Centre.

The President then spoke for a few minutes and congratulated this newest of the Sub-Centres on the high level of technical and social activities which had been accomplished in so short a time.

Dancing started at 9.30 p.m. and continued until 1 a.m. under the supervision of the senior Vice-Chairman, Mr. R. A. W. Connor. In view of the great success of this function, it will most probably be repeated next year. N. H.

SCOTTISH CENTRE

A notable event in the programme of the South-East Scotland Sub-Centre occurred on the 8th January, when Professor M. G. Say repeated the Address that he had previously given as Chairman of the Supply Section, *Too Much and Too Little*. The interest was enhanced by the fact that Professor Say permitted a discussion, which gave rise to many interesting comments. On this evening also, the Sub-Centre welcomed Sir Hamish Maclaren, Vice-President, who, on the previous evening, had visited the South-West Scotland Sub-Centre at Glasgow and who, on the succeeding evening, visited the North Scotland Sub-Centre at Dundee.

Even in the Scottish Centre time is found for relaxation, and on the 5th February the Graduate and Student Section held a joint dance in Glasgow with the Student Sections of The Institutions of Civil and of Mechanical Engineers in South-West Scotland. The Centre Chairman and other senior representatives were present at this function. In Edinburgh on the 6th February the South-East Scotland Sub-Centre held a joint dance with the East of Scotland Association of Civil Engineers. Both functions are now well-established annual events, and this year showed no falling off in enjoyment or enthusiasm. E. O. T.

NORTH STAFFORDSHIRE SUB-CENTRE

The *British Columbia—Vancouver Island 138 kV Submarine Power Cable* formed the subject of the meeting at Stone on the 18th November 1957. The paper was presented by Mr. R. M. Fairfield and Mr. E. L. Davey on behalf of themselves and their co-authors, Mr. T. Ingledow, Mr. K. S. Brazier and Mr. J. N. Gibson. An elaborate collection of models and photographs aroused considerable interest before and after the lecture. These illustrated the type of joint used and also facilitated study of the methods adopted in manufacturing, shipping, and laying the gas-filled cables in continuous lengths of up to 15 miles. Many details were also clarified by the coloured sound film shown during the lecture. The very active discussion which ensued was opened by Mr. C. C. Pimble and was fully dealt with by the authors. Mr. P. D. Gilbey, in formally thanking them, referred specially to the trouble they had taken in conveying and displaying the lorry load of equipment which had added so much to the enjoyment of the paper.

At Stoke-on-Trent on the 9th December the Chairman, Mr. H. A. P. Caddell, invited Mr. L. B. Hobgen to read the paper on *Cathodic Protection* written by him in collaboration with Mr. K. A. Spencer and Mr. P. W. Heselgrave. While the use of this method for the protection of steel pipelines from corrosion has increased greatly in recent years, the immediate interest at this meeting was to Post Office and supply engineers concerned with underground cables laid direct in the ground or in ducts. In the discussion, which was opened by Mr. J. McKinlay Allan and Mr. R. J. Gent and to which eight speakers contributed, the opposite aspects of the problem, those of protecting cable sheaths on the one hand and of preventing damage to cable sheaths by stray currents from protected equipment on the other, were well ventilated, and personal experiences were quoted. The numerous questions covering the wide range of the subject were very adequately dealt with by Mr. Hobgen in his reply. Mr. A. Asbury proposed a vote of thanks to the author for a most lively presentation of the subject and complimented him on the coloured sound film used to explain so clearly the chemical actions involved. L. G.

East Anglian Dinner-Dance

Standing, l. to r.: Capt. N. Hiller, Mr. G. E. Middleton, Mr. W. R. Brasher, Professor E. B. Moullin, the Mayor of Cambridge and Mr. T. E. Goldup.

Seated, l. to r.: Mrs. Brasher, Mrs. Hiller, the Mayoress of Cambridge, Mrs. Goldup, Mrs. Middleton and Mrs. Moullin.

OVERSEA ATTENDANCE REGISTER

During the period 17th January to 14th February 1958 the following members called at the Institution building and signed the Attendance Register of Oversea Members:

BASSON, E. I. (Cape Town)
BRIGGS, J. (Lagos)
CATER, C. (Sur Clarens, Switzerland)
DARNELL, W. B. (Abadan, Iran)
DESHPANDE, M. V. (Ahmedabad, India)
INGHAM, F. (Kuwait)
LENNOX, D. (Nairobi)
MARTINDALE, Lt.-Col. J. P. A. (Melbourne)
OAK, R. S. (Bombay)
PHILPOTT, J. G. (Maracaibo, Venezuela)
RODGERS, J. E. (Lagos)
SEDDON, Col. R. N. (Singapore)
SOMERVILLE, A. W. M. (Johannesburg)
SWITSUR, S. C. (Lagos)

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